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AIR SHOCK FILLING OF A MODEL ROOM.(U)
SEP 77 V KUCHER, J HARRISON

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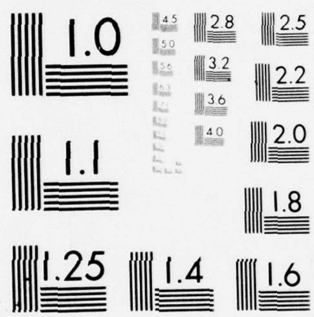

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REPORT NO. 2011

AIR SHOCK FILLING OF A MODEL ROOM

V. Kucher
J. Harrison

September 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) jk

An Eulerian code was used to numerically investigate the air shock filling by a 5-psi overpressure shock wave of a two-dimensional room (4 in. by 4 in.) having a 1-in. centrally located entrance. Numerical results are presented graphically of pressure and velocity fields, vortex motion, and pressure histories at given locations in the room. Comparisons are made with experimental results which were obtained by shadowgraphs and pressure transducers.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The Ballistic Research Laboratory has been conducting experiments to determine the effects of various parameters on the process of shock wave filling of rooms. These parameters include the dimensions of the room, the width and location of the entrance, the location and dimensions of baffles, and shock overpressure. This work is being done under the direction of George A. Coulter, DPCA project officer.

To complement these experiments, the authors were asked to provide, by means of a computer-oriented mathematical model, a detailed picture of the shock filling of a room process. Although many of the experiments involve three-dimensional models of the rooms, some of the experiments are performed on essentially two-dimensional models. We shall be dealing with the latter in this report which will consider a 4 in. by 4 in. enclosure with a 1-in., centrally located, entrance which is exposed to a 5-psi overpressure air shock wave.

Several two-dimensional codes or programs, which are operational at BRL and were developed to handle, among other problems, blast wave problems include OIL,[1] RIPPLE,[2] TOIL,[3] DORF,[4] and HELP,[5,6] all of which are Eulerian formulated; that is, a computational grid or coordinate system is fixed in the region of interest, and the flow variables are calculated for each cell in the grid as the fluid moves through the cells.

The RIPPLE code was selected as the mathematical model for calculating the flow field since it has the capability for including rigid walls (internal reflective boundaries) in the grid.

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1. *W. E. Johnson, "OIL, A Continuous Two-Dimensional Eulerian Hydrodynamic Code," Gulf General Atomic, GAMD-5580 Revised, January 1965.*

2. *M. W. Evans, "RIPPLE - A Two-Dimensional Computer Program for Calculating Compressible Flow and Detonation Problems," General Atomic Report No. GAMD-8165, September 1967.*

3. *W. E. Johnson, "TOIL, A Two-Material Version of the OIL Code," Gulf General Atomic, GAMD-8073 Addendum, November 1967.*

4. *Wallace E. Johnson, "Code Correlation Study," Air Force Weapons Laboratory Technical Report No. 70-144, April 1971.*

5. *L. J. Hageman and J. M. Walsh, "HELP, A Multi-Material Eulerian Program for Compressible Fluid and Elastic-Plastic Flows in Two Space Dimensions and Time, Volume I," Ballistic Research Laboratories Contract Report No. 39, May 1971.* (AD #726459)

6. *L. J. Hageman and J. M. Walsh, "HELP, A Multi-Material Eulerian Program for Compressible Fluid and Elastic-Plastic Flows in Two Space Dimensions and Time, Volume II: FORTRAN Listing of HELP," Ballistic Research Laboratories Contract Report No. 39, May 1971.* (AD #726460)

II. COMPUTER CODE

RIPPLE is a FORTRAN computer code developed for calculating unsteady compressible flow. It was developed by Gulf General Atomic, Inc. under contract with BRL. It evolved, chronologically, from the PIC[7] and OIL codes.

RIPPLE is Eulerian formulated. Material motion is governed by the numerical approximations to the equations of conservation of mass, energy, and momentum. These equations, along with an equation of state, allow sufficient equations for their numerical solution.

The BRL version of RIPPLE uses the equation of state for an ideal gas. Since only one ratio of specific heat at constant pressure to specific heat at constant volume, γ, can be specified in the code, only one fluid can be used during a computer run.

RIPPLE is a two space dimension code using either plane(x,y) coordinates or cylindrical (r,z) coordinates. The former option is used in this problem. The time increment, selected by the computer, is based on the Courant condition or the maximum sound speed plus the particle velocity in the grid.

The boundaries of the grid may be selected to be either transmissive or reflective. The former permits mass to flow through the boundary; the latter acts as a rigid wall.

The input for RIPPLE involves the specification of the initial density, specific internal energy, and velocity components in each cell containing any fluid and also the specification of the outline of any rigid walls internal to the boundaries of the grid.

III. PROBLEM SPECIFICATIONS

A sketch of the enclosure is shown in Figure 1. The symmetry of the enclosure permits us to examine half of the enclosure with the line of symmetry acting as a reflective boundary. The symmetry reduces the computer memory requirements for this problem.

The grid and layout for the problem are shown in Figure 2. The number of cells in the x-direction was 30; the number in the y-direction, 110. This grid required a memory of 61,000 words on the BRLESC (Ballistic Research Laboratories Electronic Scientific Computer). The length of the sides of the square cells was 0.1 in. The y-increment of the cells near the bottom of the grid was increased to numerically absorb the shock wave which was reflected from the front face of the enclosure and to act as a source for the initial shock

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7. *Anthony A. Amaden, "The Particle-in-Cell Method for the Dynamics of Compressible Fluids," Los Alamos Scientific Laboratory of the University of California, LA-3466, February 1966.*

wave. The x-increment of the cells on the right of the grid was increased to provide a material source and to numerically absorb disturbances generated at the entrance to the enclosure.

We assumed that air was an ideal gas; a value of 1.4 was used for γ.

The ambient conditions in the room and in front of the shock wave were the following:

1. Pressure = 14.696 psia
2. Density = 0.0022835 slugs/ft^3
3. Temperature = 80.72°F
4. Particle velocity = 0 ft/sec
5. Specific internal energy = 2,316,865 lb-ft/slug

Behind the shock front, the initial flow conditions were the following:

1. Pressure = 19.696 psia
2. Density = 0.0028124 slugs/ft^3
3. Temperature = 128.29°F
4. Particle velocity = 243.42 ft/sec
5. Specific internal energy = 2,520,770 lb-ft/slug

Based on one-dimensional shock theory, the shock will be traveling at a speed of 1294 ft/sec as it enters the enclosure. The shock wave which is reflected from the front face of the enclosure travels at a speed of 1587 ft/sec. The reason that so many cells were positioned in front of the enclosure was to permit the reflected wave to travel as long as possible without encountering a grid boundary from which numerical noise could be generated.

IV. NUMERICAL AND EXPERIMENTAL RESULTS

The main output of the computer for this problem was displayed as pressure fields and velocity fields. In these field plots, the spatial coordinates are cell number in the x-direction (labeled R) and cell number in the y-direction (labeled Z). For example, see Figure 3. Except for cells numbered R = 25 through 30 and Z = 1 through 8, the physical size of each cell, as mentioned previously, was 0.1 in. square, thus, in the region of interest, each cell unit in the field plots is equivalent to 0.1 in.

In the pressure field plots, the coordinate which is perpendicalar to the spatial plane is the overpressure. Figure 3 shows the initial pressure field with the shock front located nine cells (0.9 in.) from the front face of the enclosure. The shock front was located here to allow the profile of a numerical shock to develop and thus have a numerical shock enter the enclosure. Figure 4 shows the numerical shock at the entrance to the enclosure. Note that the shock is smeared over about five cells or 0.5 in. This smearing of the shock over four

or five cells is characteristic of the RIPPLE code. A finer physical resolution of the shock front would require a smaller cell size and thus more cells in the grid and a larger memory requirement.

Figure 5 shows the shock wave which was reflected from the front face of the enclosure. Based on the one-dimensional shock wave theory, the reflected shock pressure is 26.078 psia with the particle velocity being zero. The RIPPLE results show a pressure of about 24.4 psia in this region. The pressure in the enclosure, along the axis of symmetry, is about 17 psia, a decrease of about 2.7 psi from the initial shock pressure.

The velocity field, corresponding to the pressure field shown in Figure 5, is shown in Figure 6. Since we are using an Eulerian grid, the vectors are shown as emanating from the center of each cell. With the base of these vectors fixed in location, these vectors can change in magnitude and direction, but they cannot translate. Here we note that there is considerable flow between the front face of the enclosure and the front of the reflected shock wave. Since the one-dimensional theory indicates zero particle velocity behind a reflected shock wave, we would not expect the pressures from RIPPLE and the one-dimensional theory to agree in this region.

In Figure 6, at 0.3041 ms, the front of the reflected shock wave is about 28 cells (2.8 in.) from the front face of the enclosure. The one-dimensional theory locates the reflected shock front at 4.69 in. (about 47 cells) from the front face of the enclosure. Thus we see that the one-dimensional shock-wave theory cannot be used here to predict shock conditions.

At coordinates (8,71) in Figure 6, we note the beginning of the formation of a vortex. Figure 5 shows a low pressure in this region. More will be said about this vortex later.

The computer code was set to print the output every 25 cycles of computation. The time increment for each cycle was not constant since, as mentioned previously, the computer was programmed to select the time increment. A detailed account of the pressure field and the corresponding velocity field in the enclosure is shown in Figures 7 through 84 as these fields change with time. This series of figures begins at Cycle 25 (Figures 7 and 8) where the shock wave has not, as yet, entered the enclosure and the initial conditions exist.

In Figures 9 through 22. shadowgraph data[8] of the shock waves and vortex are plotted in the XY plane. The shock waves appear as arcs and the vortex appears as a circle or part of a circle. The general direction (but not the magnitude of the velocity) of the shock waves is indicated by large arrows.

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8. *George A. Coulter, "Air Shock Filling of Model Rooms," Ballistic Research Laboratories Memorandum Report No. 1916, March 1968.* (AD #670937)

The first indication of the formation of a numerical vortex appears in Figure 16 at point (0.75,0.1). The corresponding pressure field (Figure 15) shows a low pressure region at this location. The motion of the numerical vortex can easily be followed in the figures of the velocity fields as it moves towards the rear of the room. The corresponding figures of the pressure fields show the location of the vortex by a low pressure region.

A comparison of the paths of the center of the vortex, as determined by RIPPLE and by experiment, is shown in Figure 85. A graph of the displacements (in the Y-direction) as a function of time of the center of the vortex is shown in Figure 86. The general slope of the curves indicates that the vortex is moving toward the rear of the enclosure at a speed of about 0.24 in./ms or 20 ft/sec* and eventually settles at a constant Y-position for the remainder of the computer run.

A comparison of the locations of the shock waves from shadowgraphs and computer output can be made from the pressure fields. The numerical 5-cell spread of the shock waves (noted by a pressure change) is seen to bound the experimental shock waves. This spread makes locating shock waves more and more difficult as time progresses.

Figure 72 shows that some flow has started out of the entrance of the enclosure; this becomes more noticeable in Figure 84.

Figure 87 shows the positions of 12 pressure transducers that were used in the experiment. Numerical and experimental pressure histories at each of these locations are shown in Figures 88-93. In general the agreement between the experimental and numerical curves is good except when the vortex passes close to the location of a pressure transducer. Then the numerical pressures do not drop as much as indicated by experiment. The use of a finer grid in the enclosure may produce better agreement at these times.

V. CONCLUSIONS

RIPPLE was used to numerically investigate the filling by a 5-psi overpressure air shock wave of a two-dimensional room (4 in. by 4 in.) having a 1-in. centrally located entrance. The numerical results were presented graphically of pressure and velocity fields, vortex motion, and pressure histories at given locations in the room. Comparisons were made with experimental results which were obtained by shadowgraphs and pressure transducers. Overall the agreement was good except when the vortex influence was felt by the pressure transducers. Then, the numerical pressures did not decrease as much as experimented indicated. The use of a finer grid may produce better agreement at these times.

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* *The units used in this report are consistant with the units used in Reference 8.*

The numerical spread of the shock waves makes locating the exact positions of the shock waves impossible, however, as seen from comparisons with shadowgraph data, a general location of the waves is possible. The use of a finer grid would help in locating the shock waves more accurately; however, there would aways be a spread of uncertainty.

This numerical investigation shows that detailed data, that is not possible to obtain by experiment, can be obtained theoretically. The numerical results could be useful in a parameter study or for determining expected pressure levels and optimum positioning of pressure transducers for sensing or not sensing vortex pressures.

ACKNOWLEDGMENTS

The authors would like to acknowledge George Coulter for suggesting the problem and providing the experimental data and Allen Delp and Richard Cook for their computer and graphical support.

REFERENCES

1. W. E. Johnson, "OIL, A Continuous Two-Dimensional Eulerian Hydrodynamic Code," Gulf General Atomic, GAMD-5580 Revised, January 1965.

2. M. W. Evans, "RIPPLE - A Two-Dimensional Computer Program for Calculating Compressible Flow and Detonation Problems," General Atomic Report No. GAMD-8165, September 1967.

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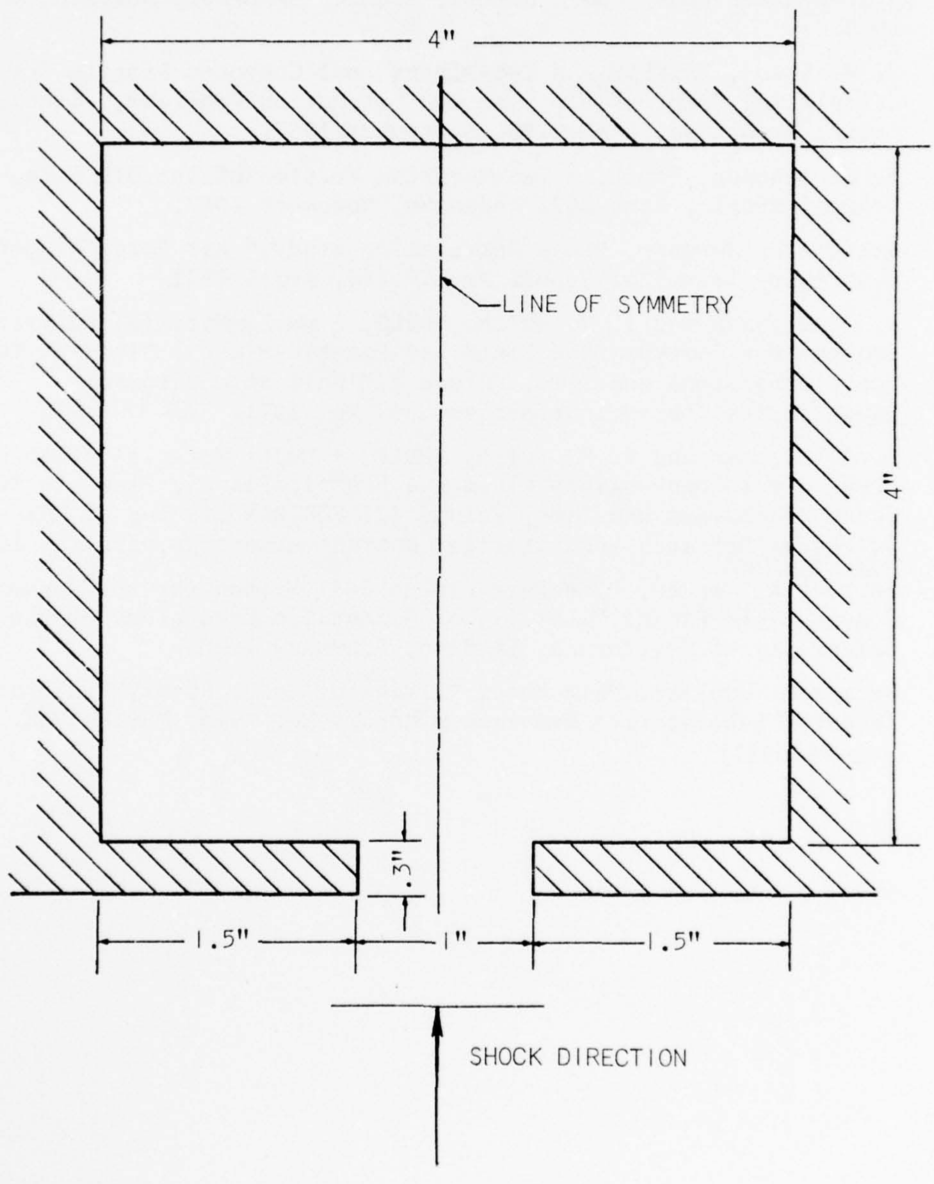

Figure 1. Two-Dimensional Model Room

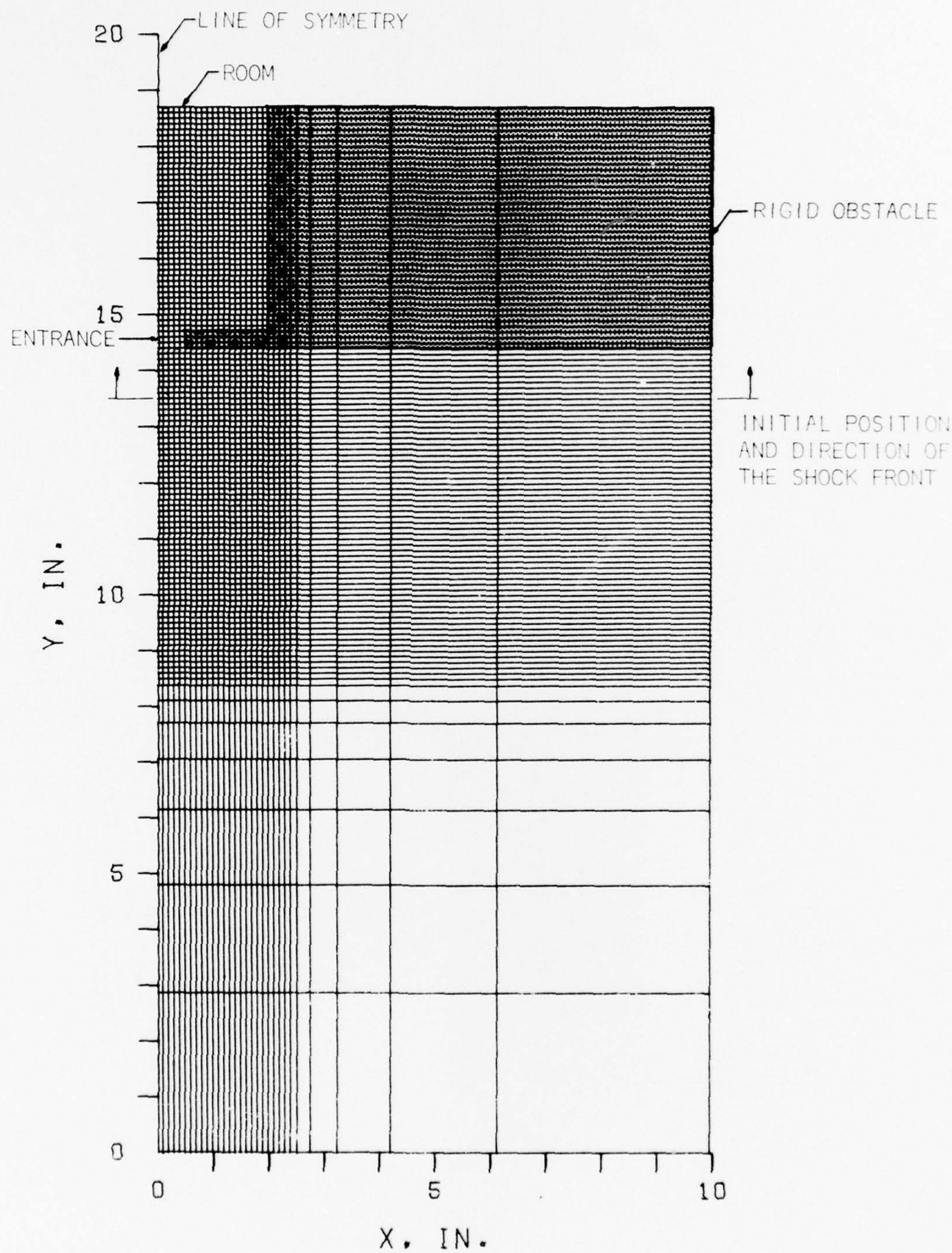

Figure 2. Computational Grid with Room Outline

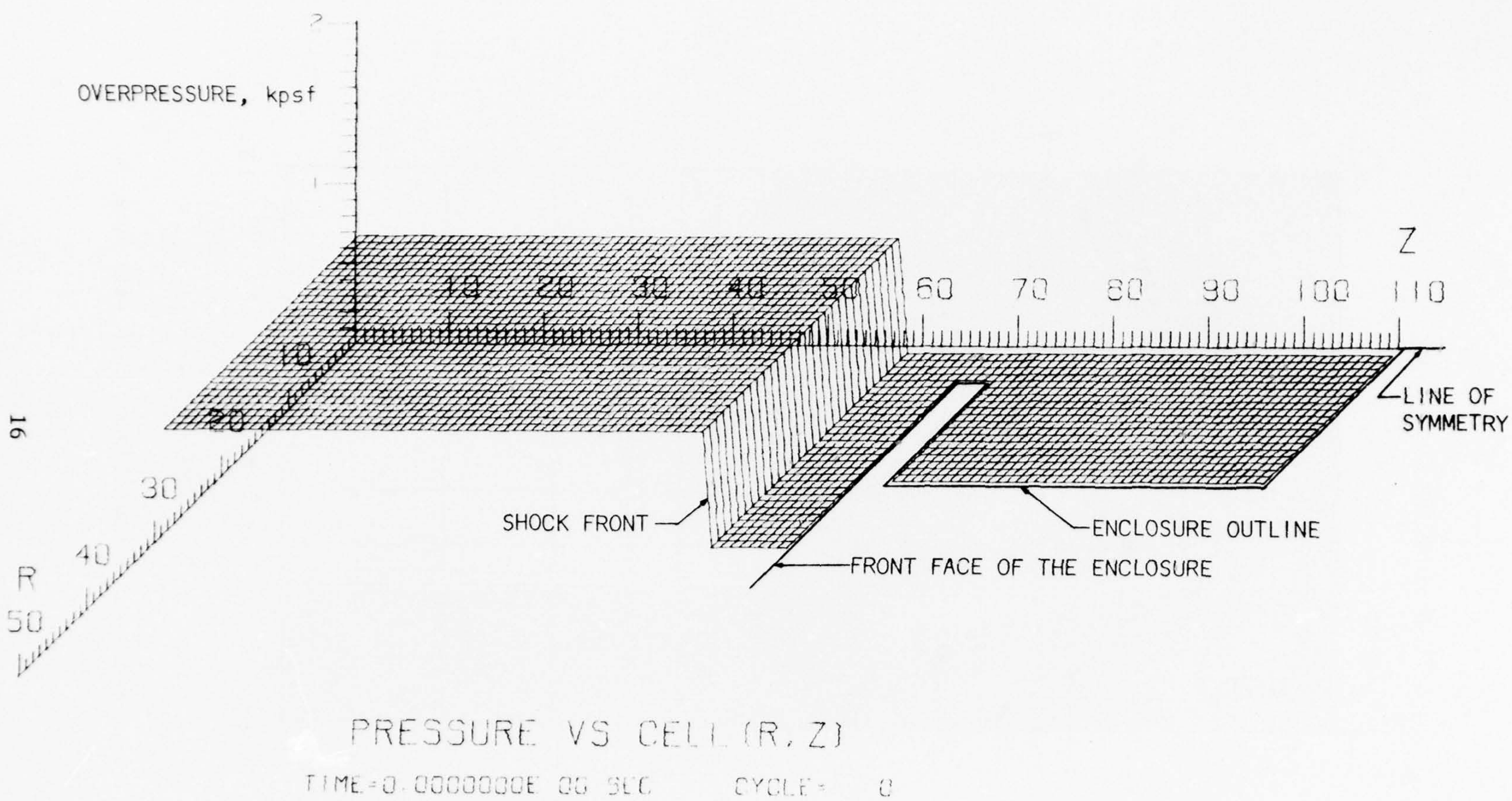

Figure 3. Initial Pressure Field

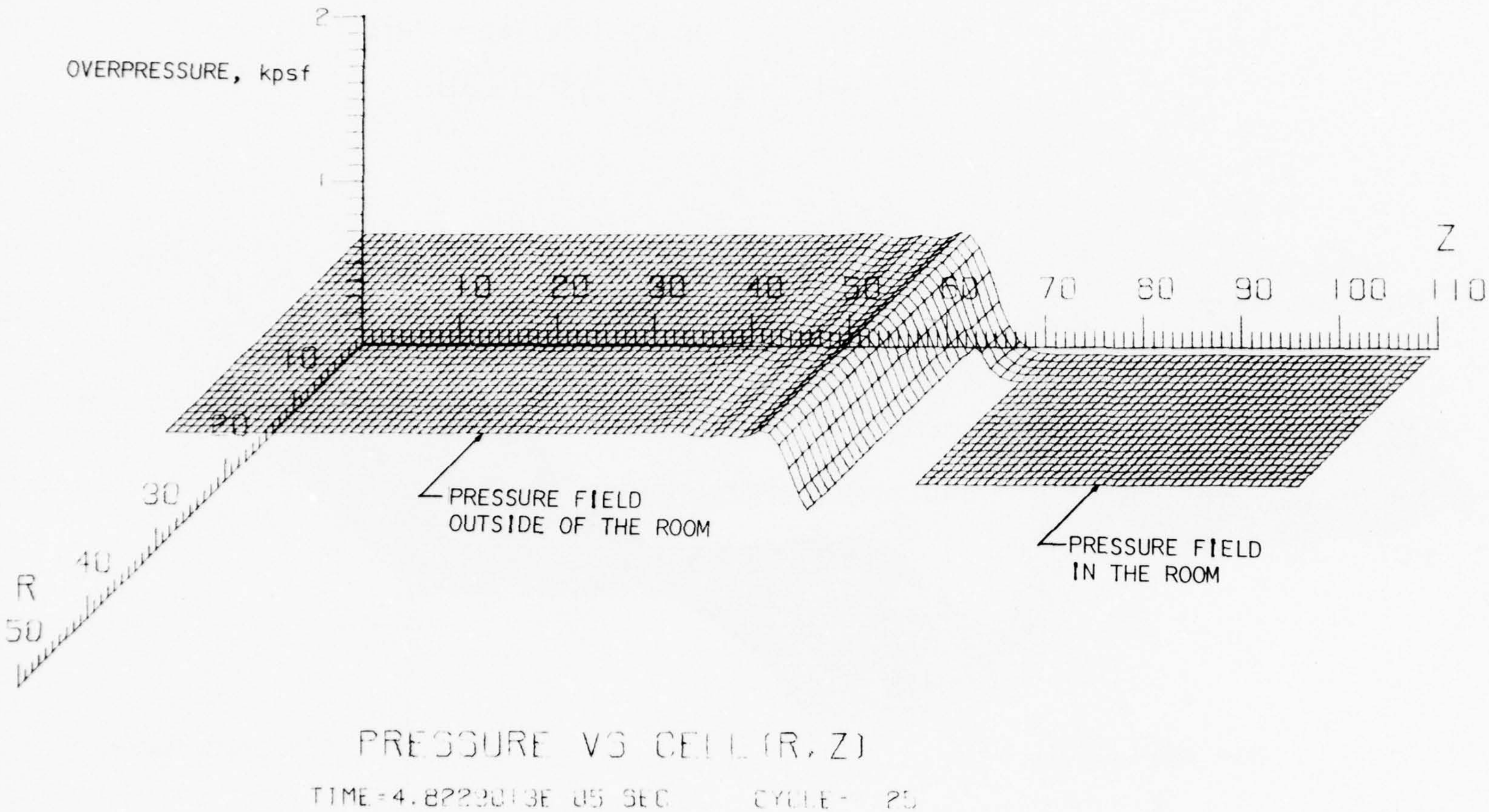

Figure 4. Pressure Field with the Shock Wave Entering the Room

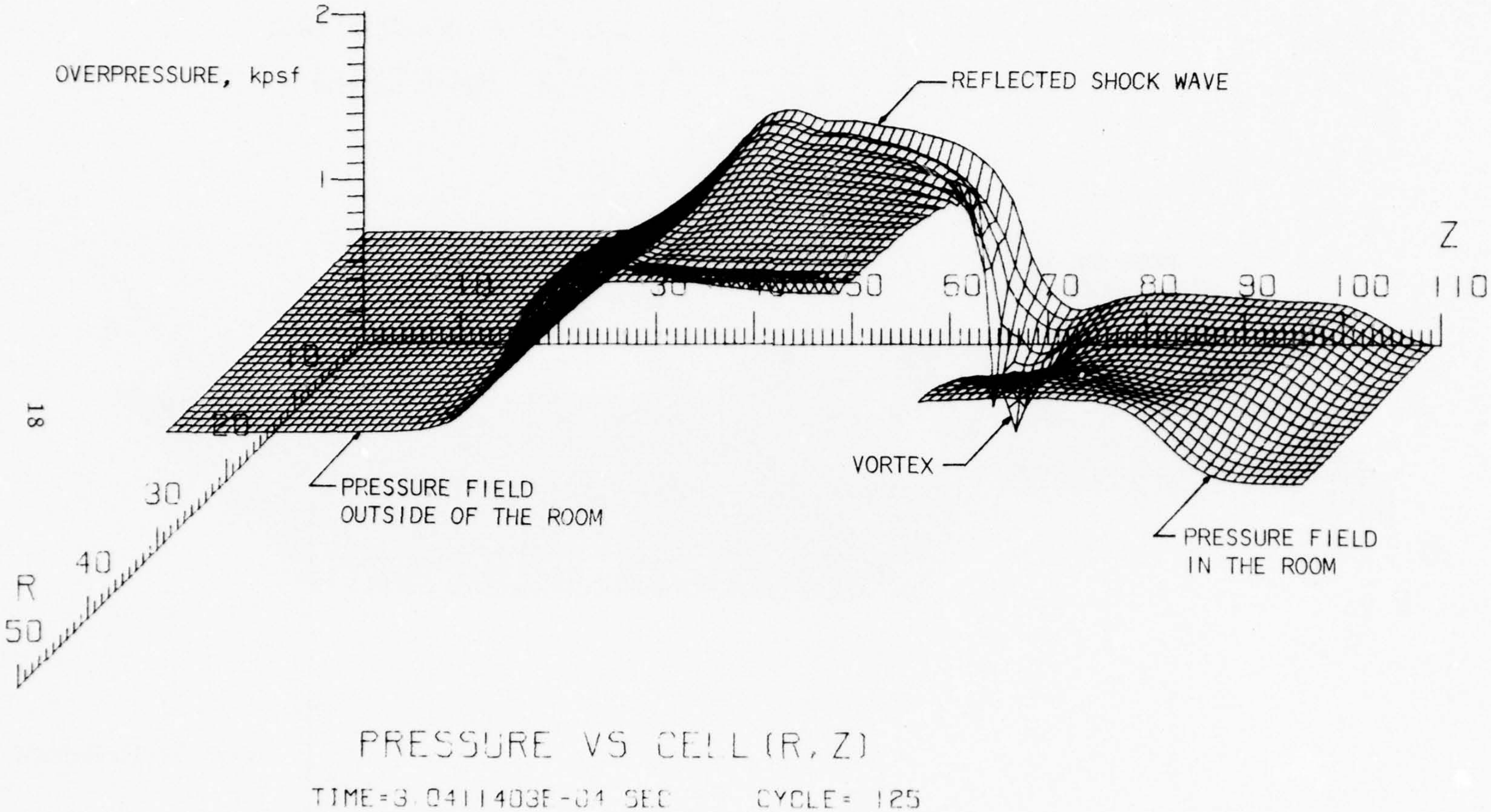

Figure 5. Pressure Field Showing the Reflected Shock Wave and a Vortex

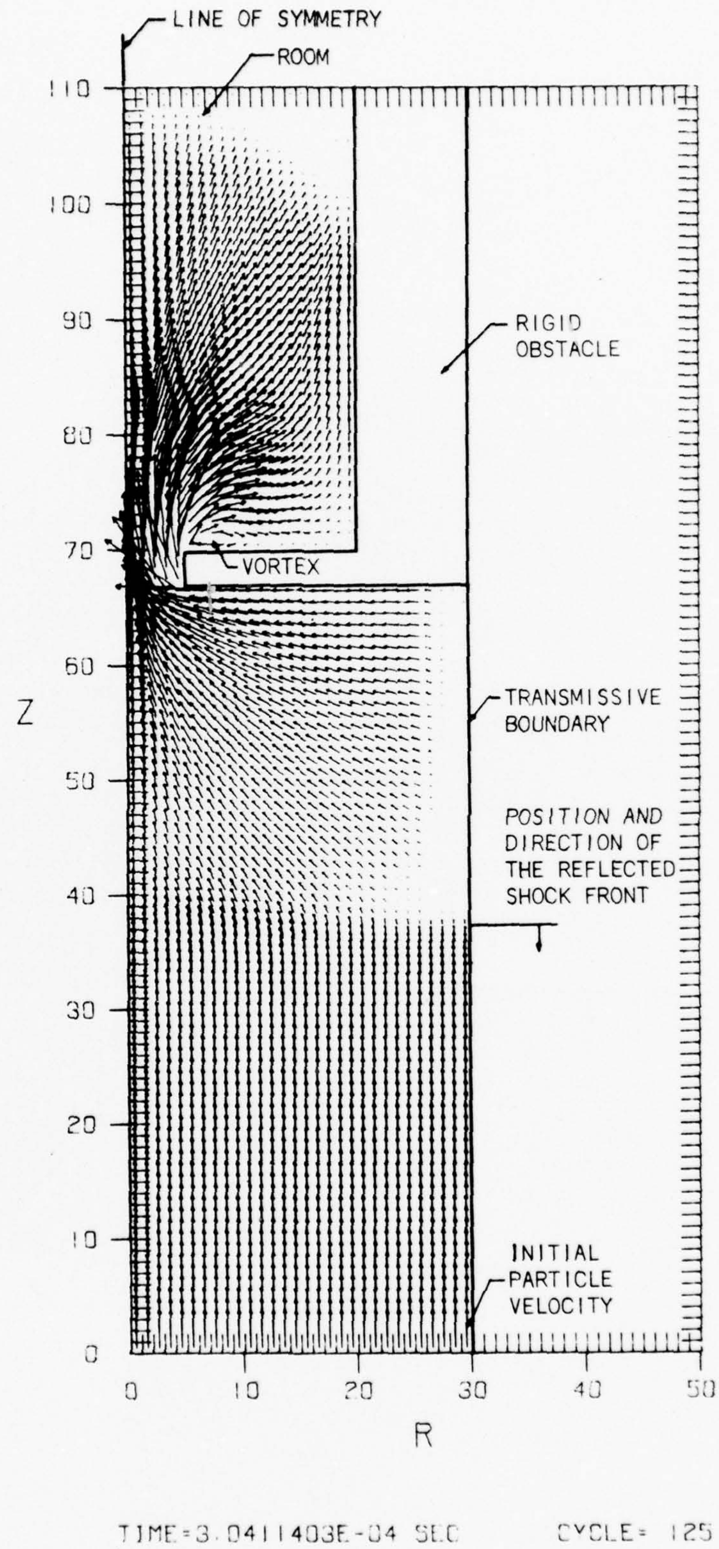

Figure 6. Velocity Field Showing the Reflected Shock Wave and a Vortex

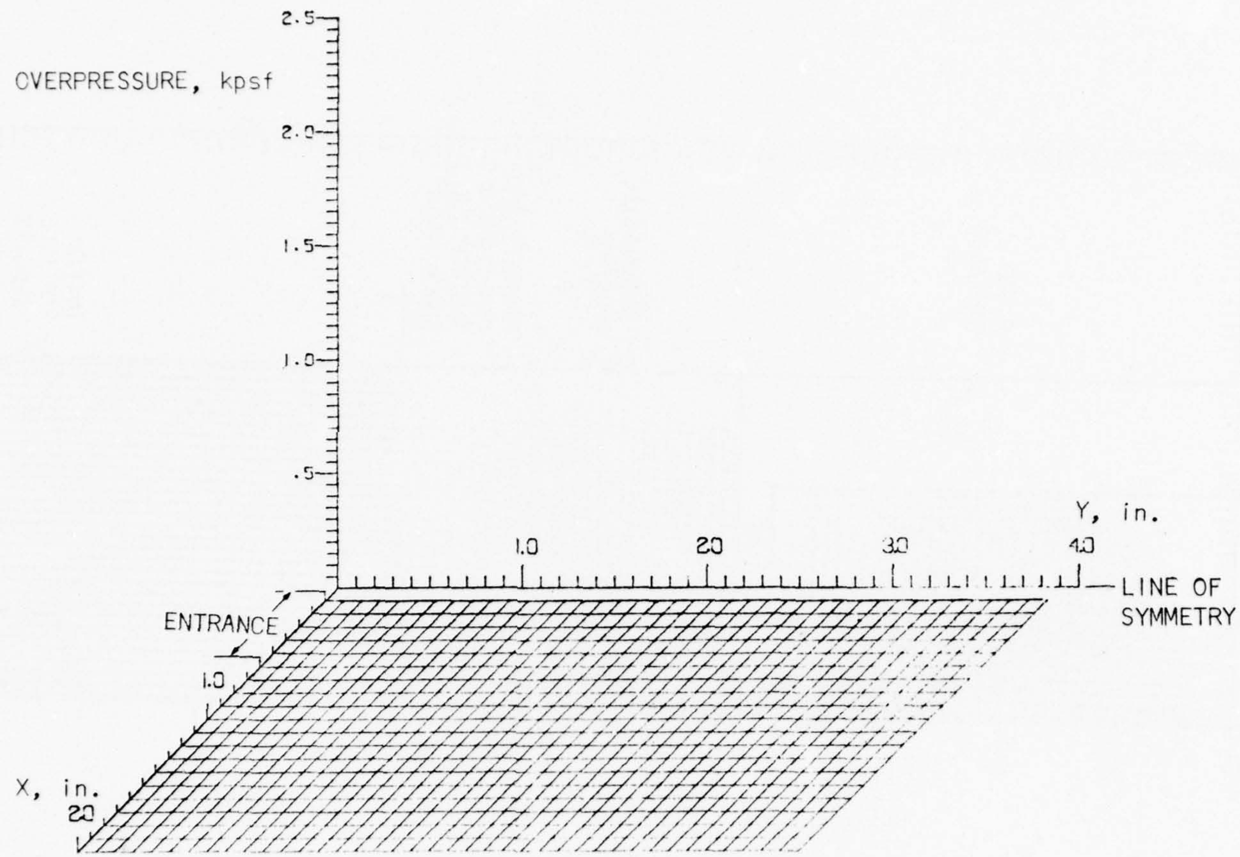

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Figure 7. Pressure Field

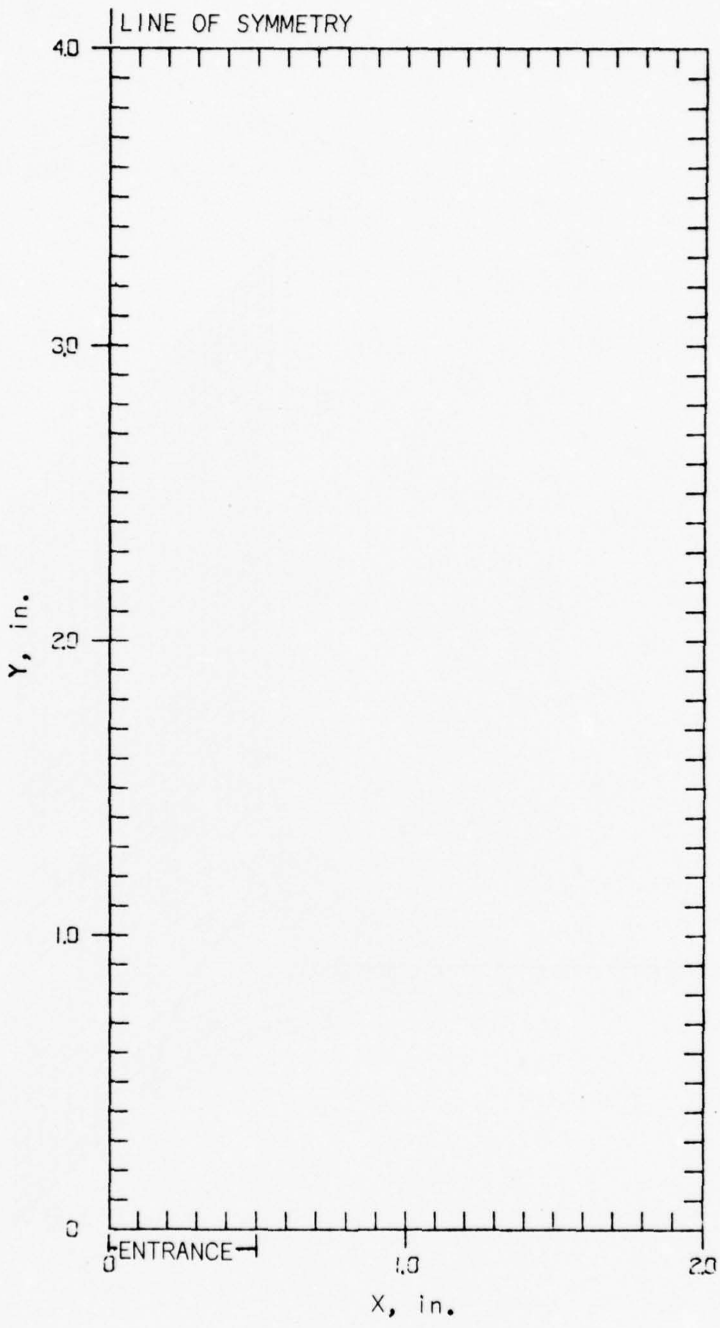

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Figure 8. Velocity Field

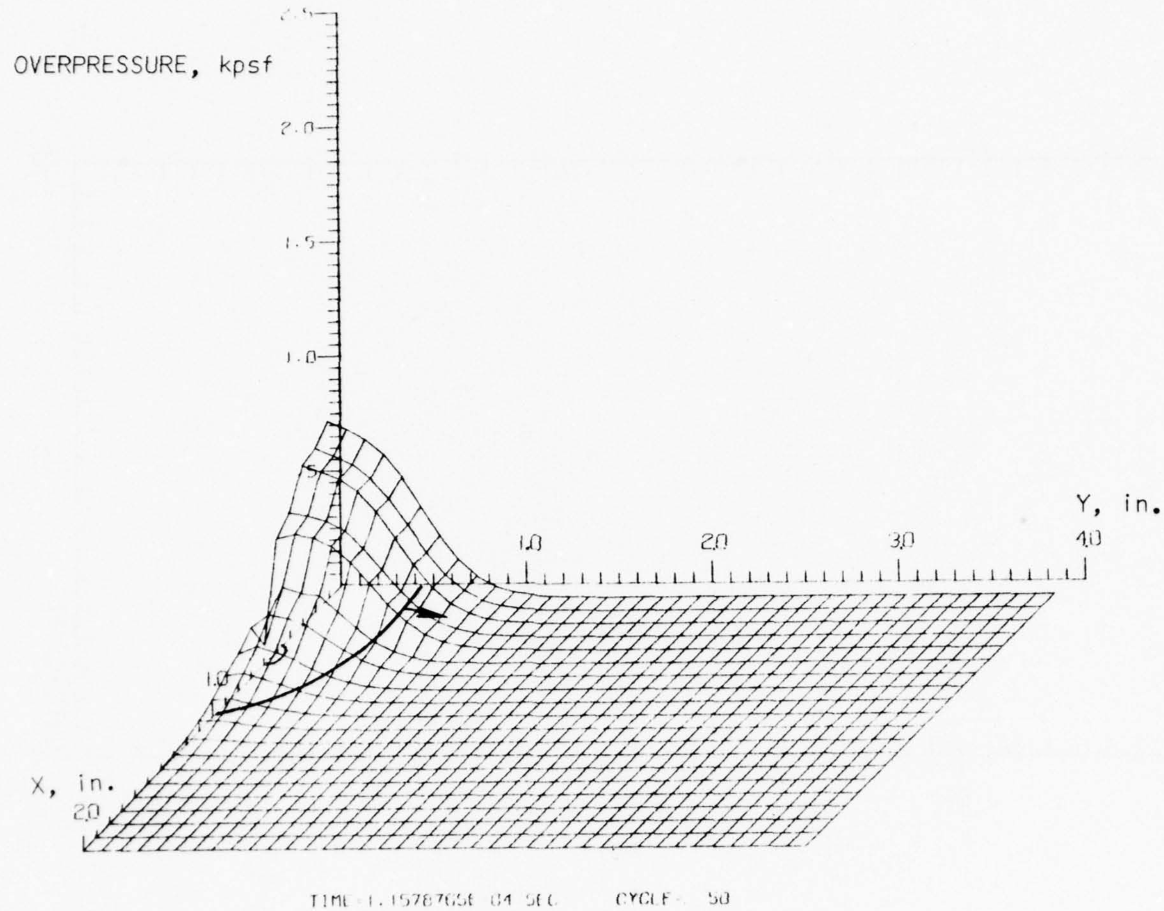
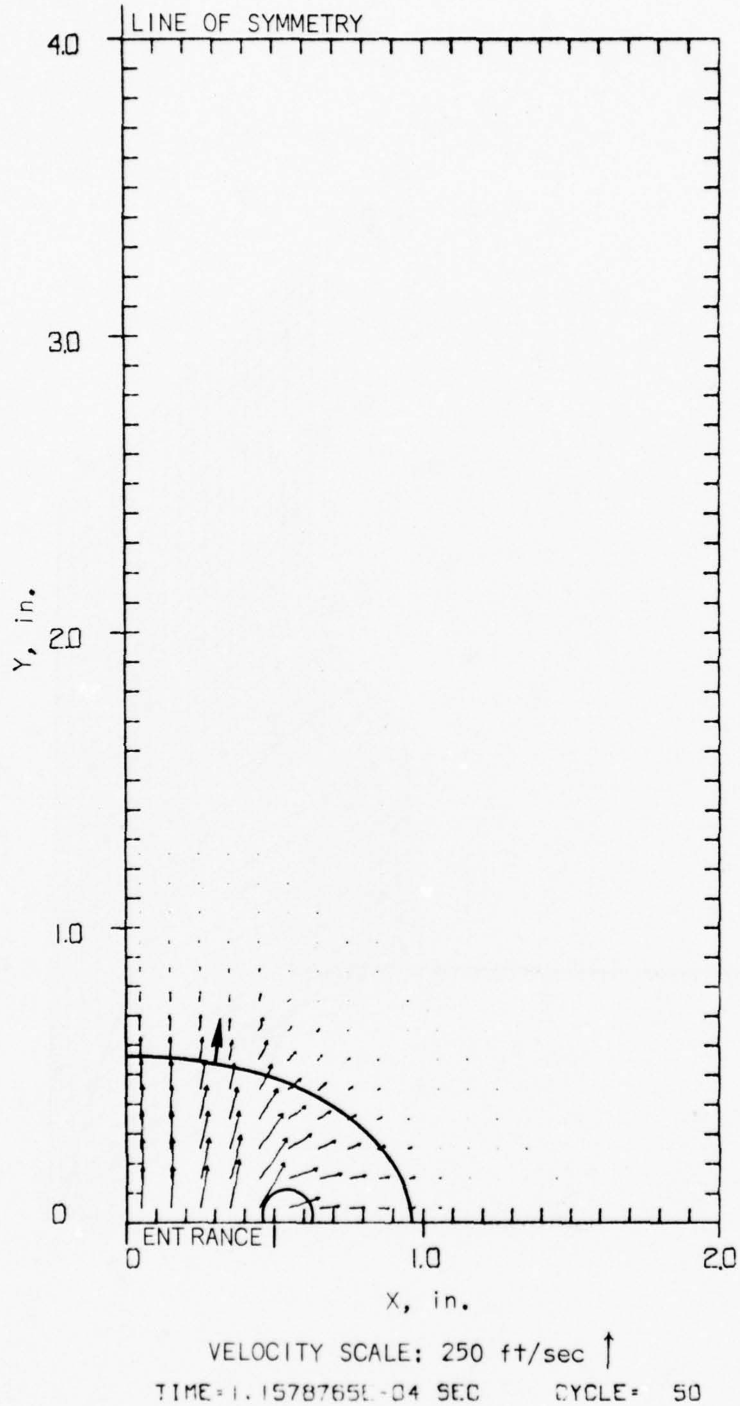


Figure 9. Pressure Field



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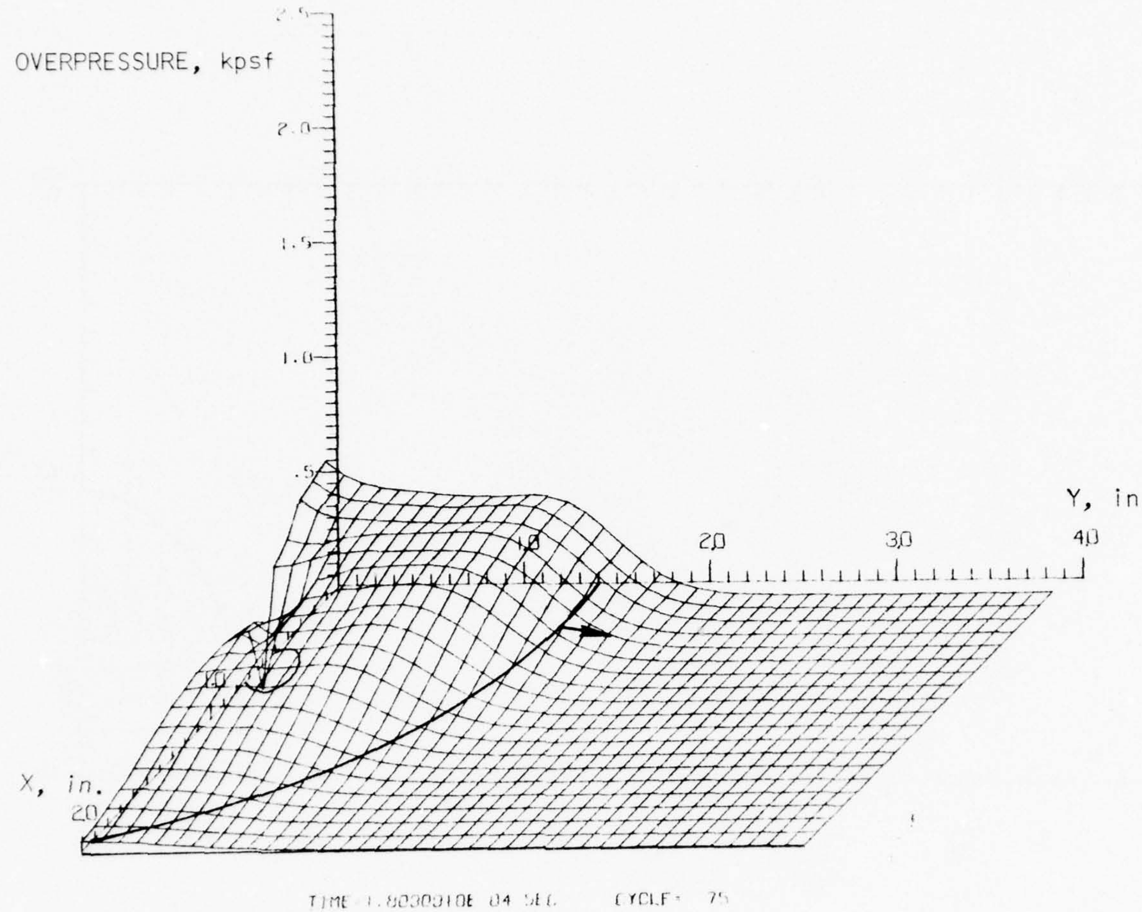
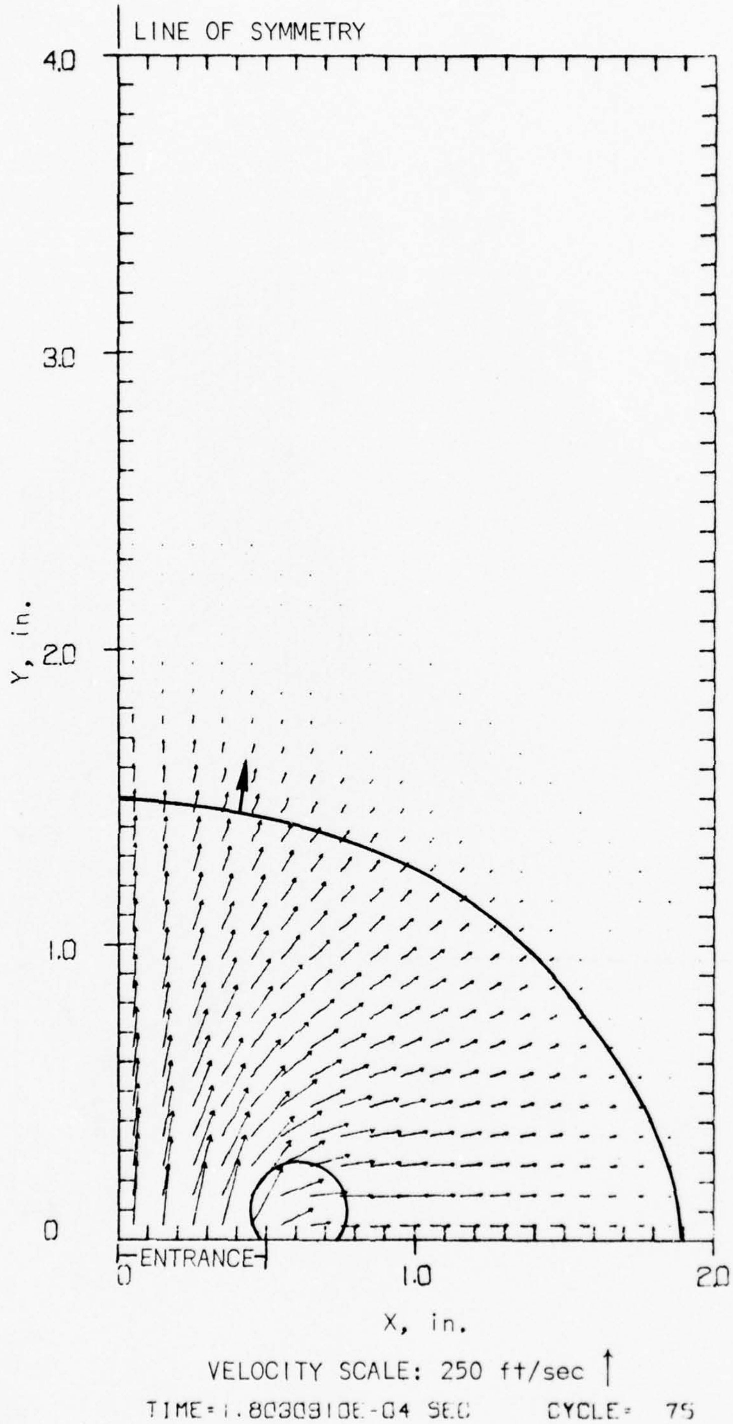


Figure 11. Pressure Field



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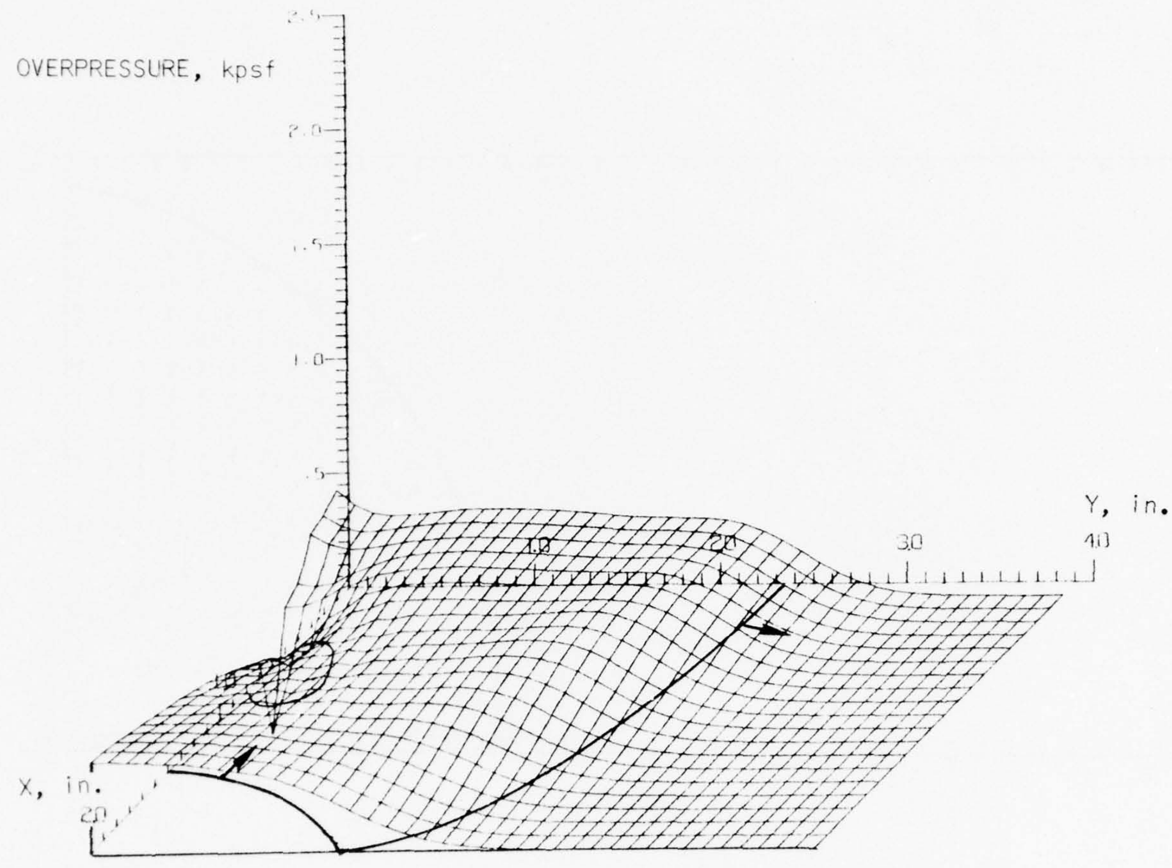

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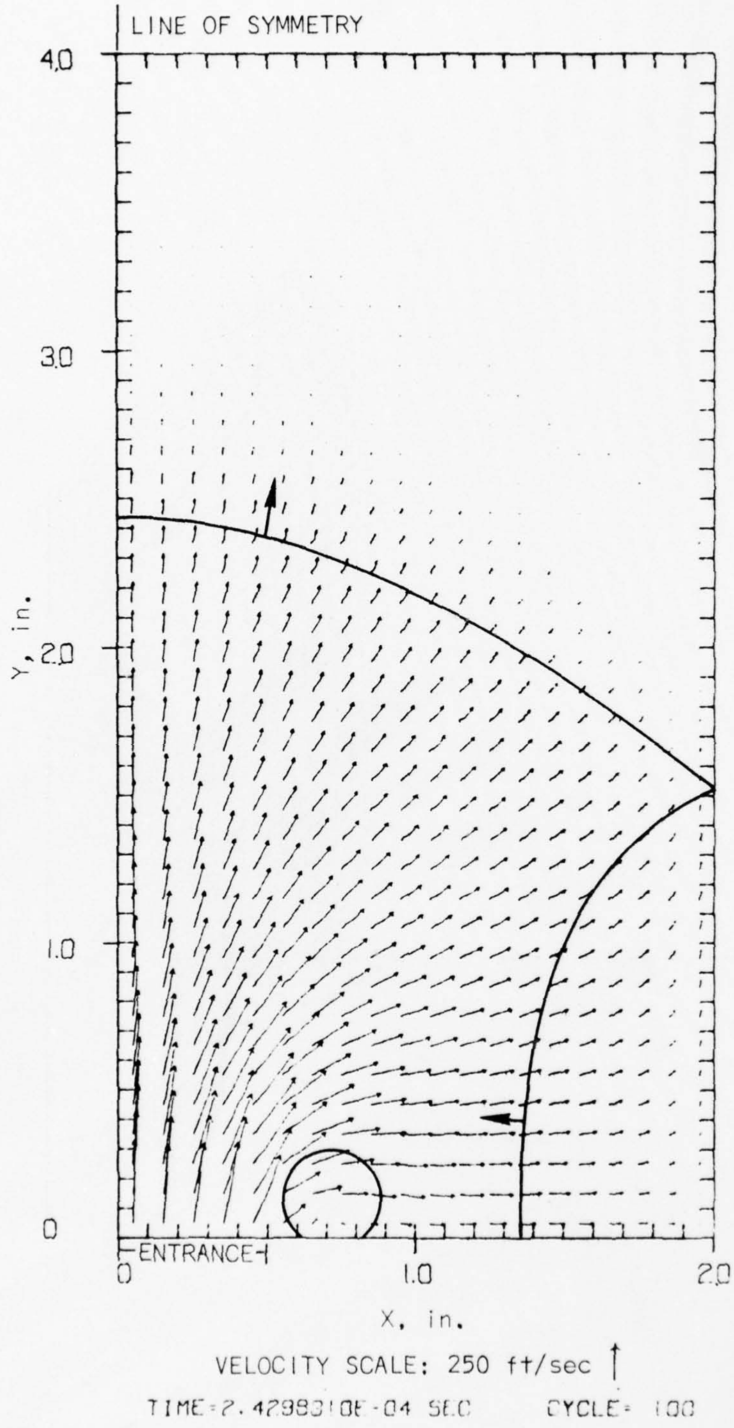

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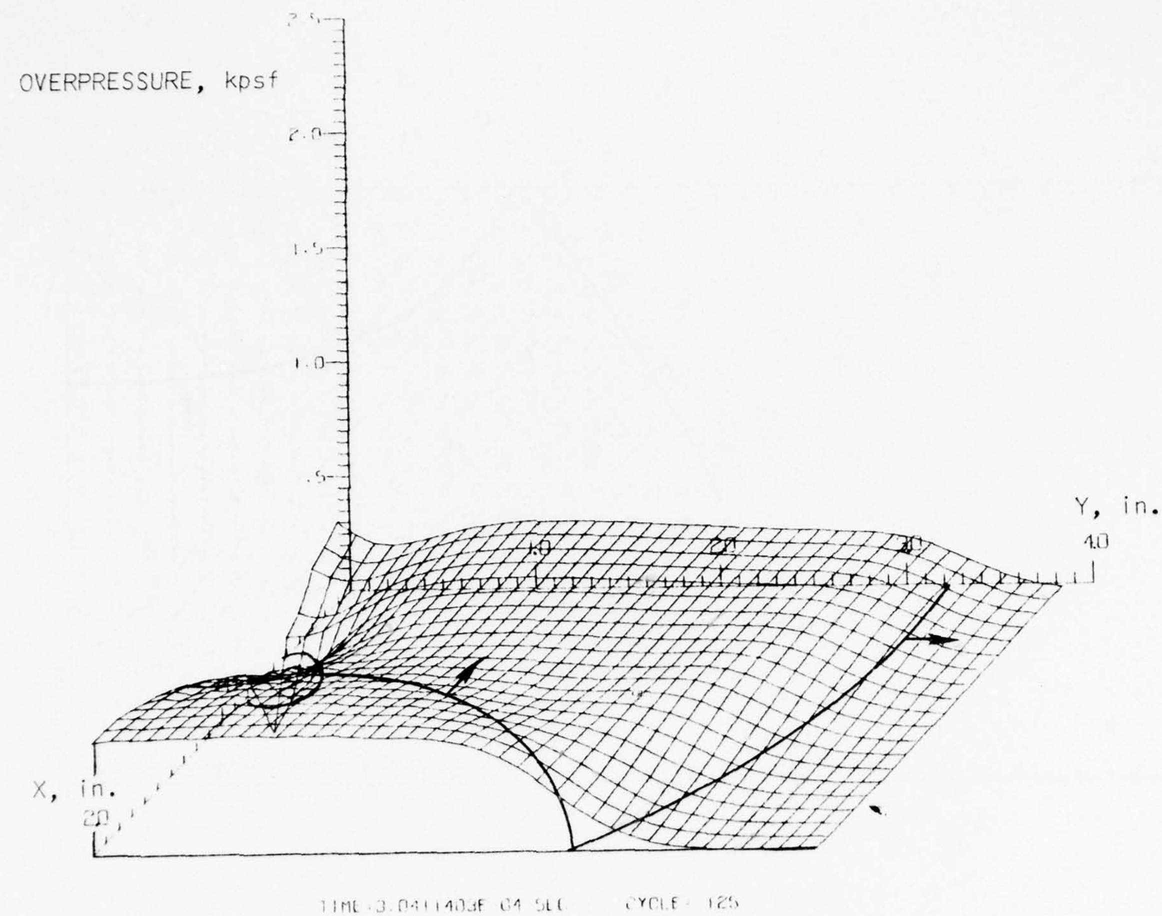
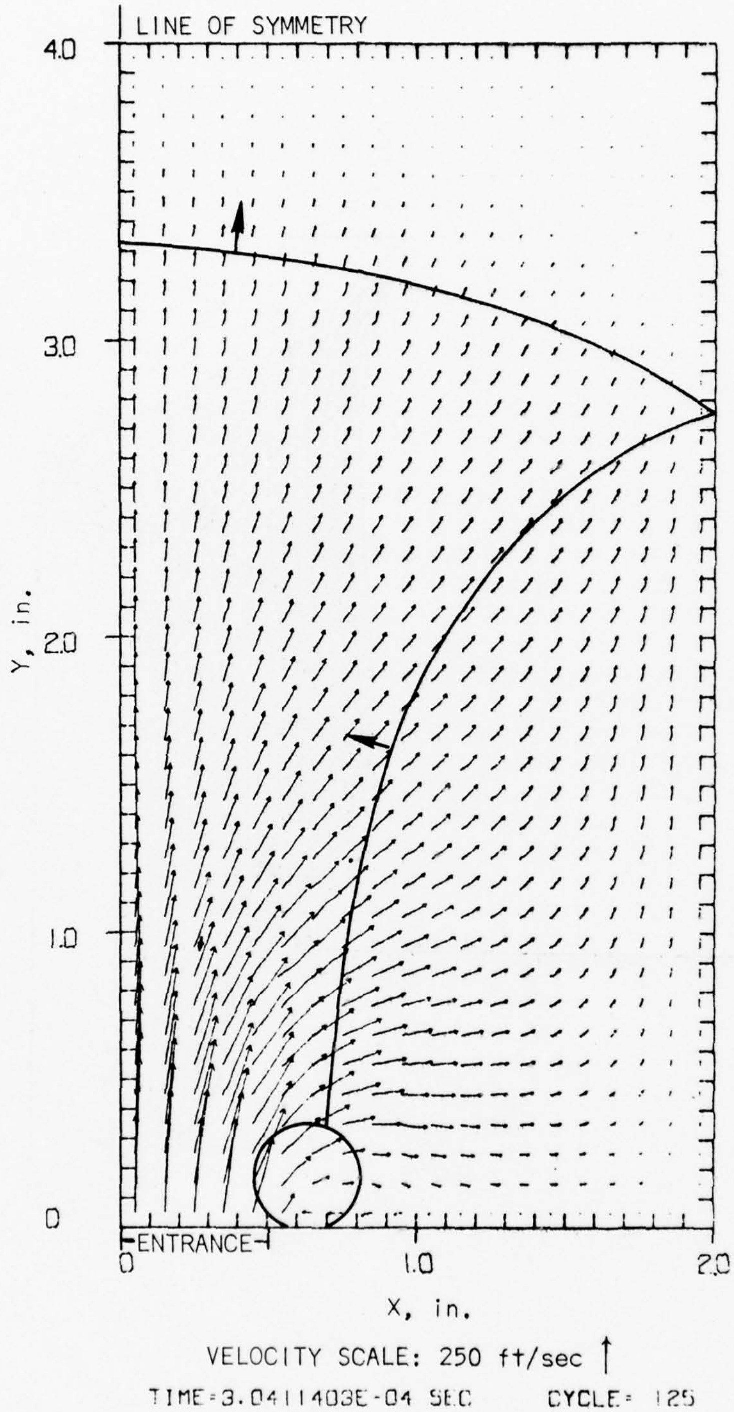


Figure 15. Pressure Field



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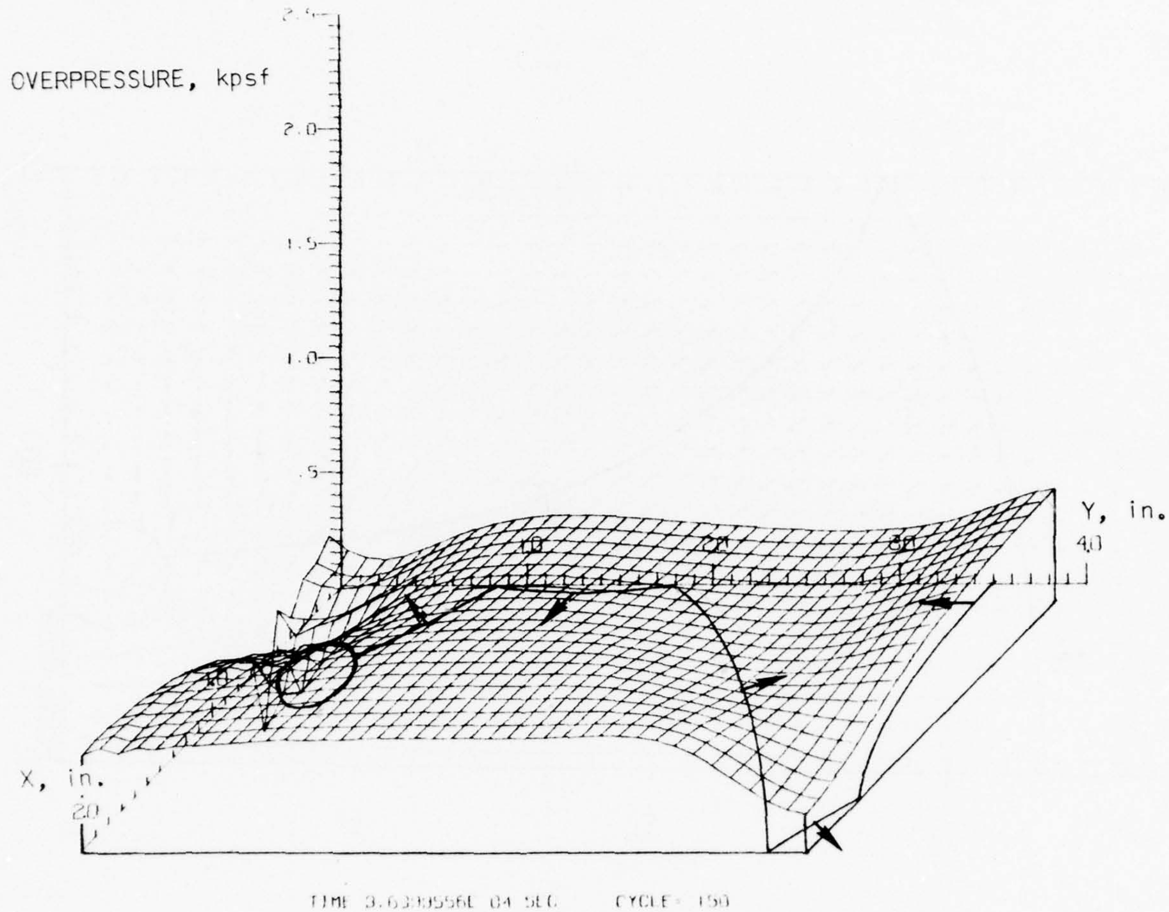

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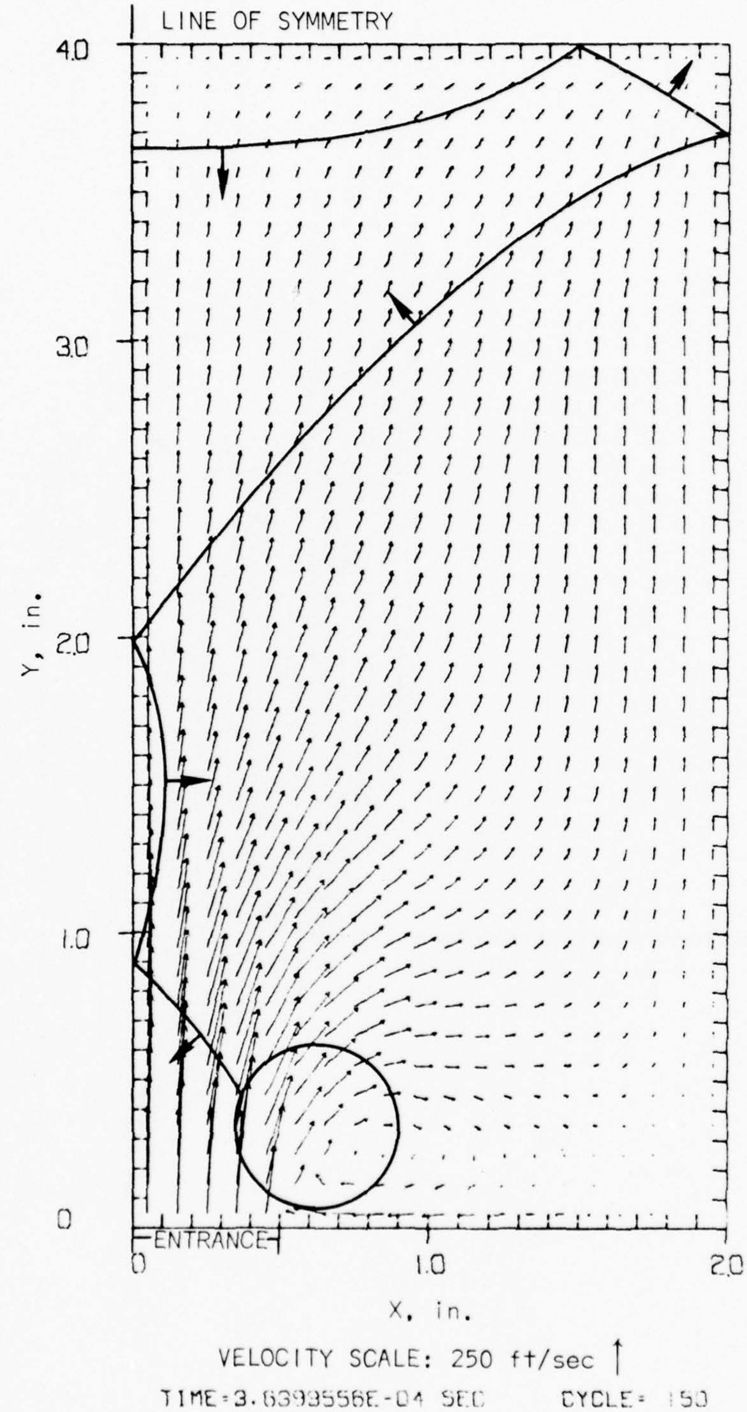

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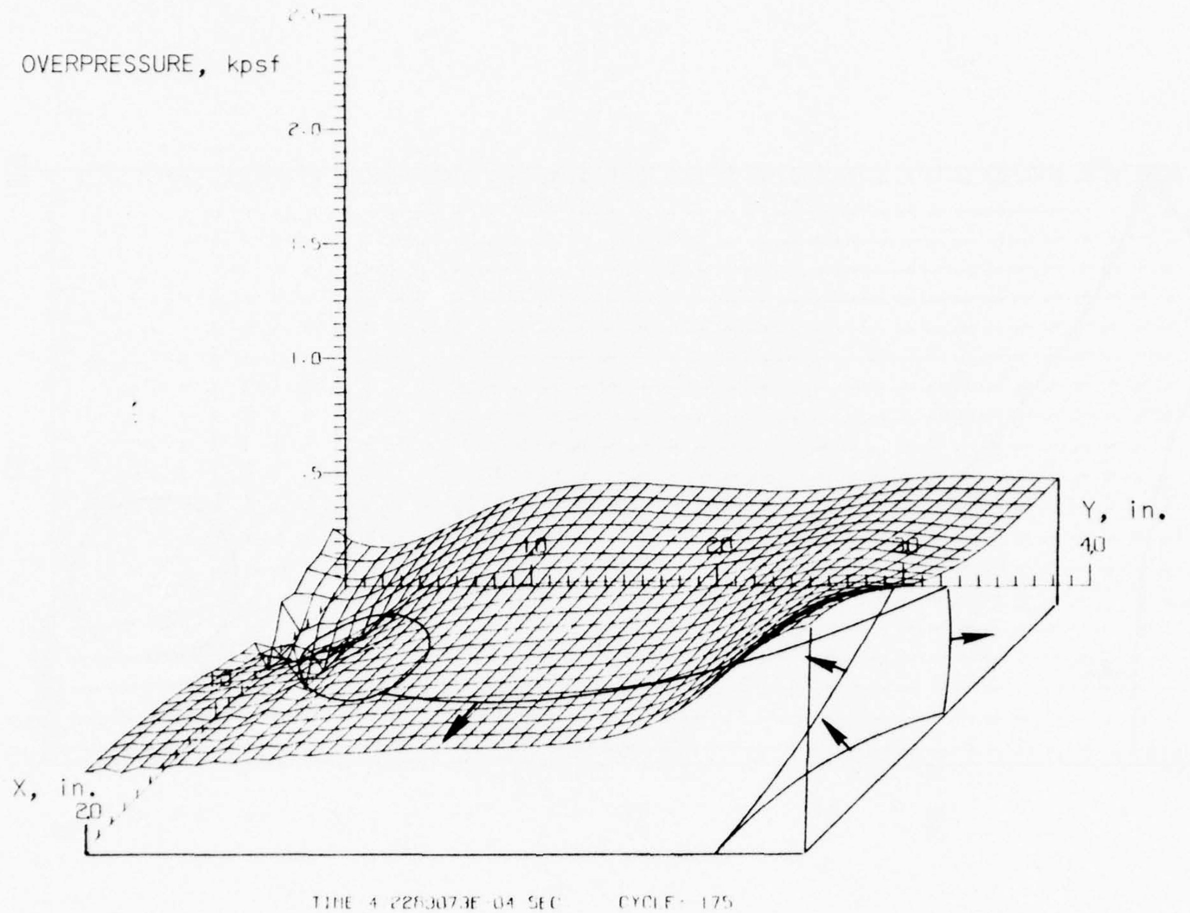

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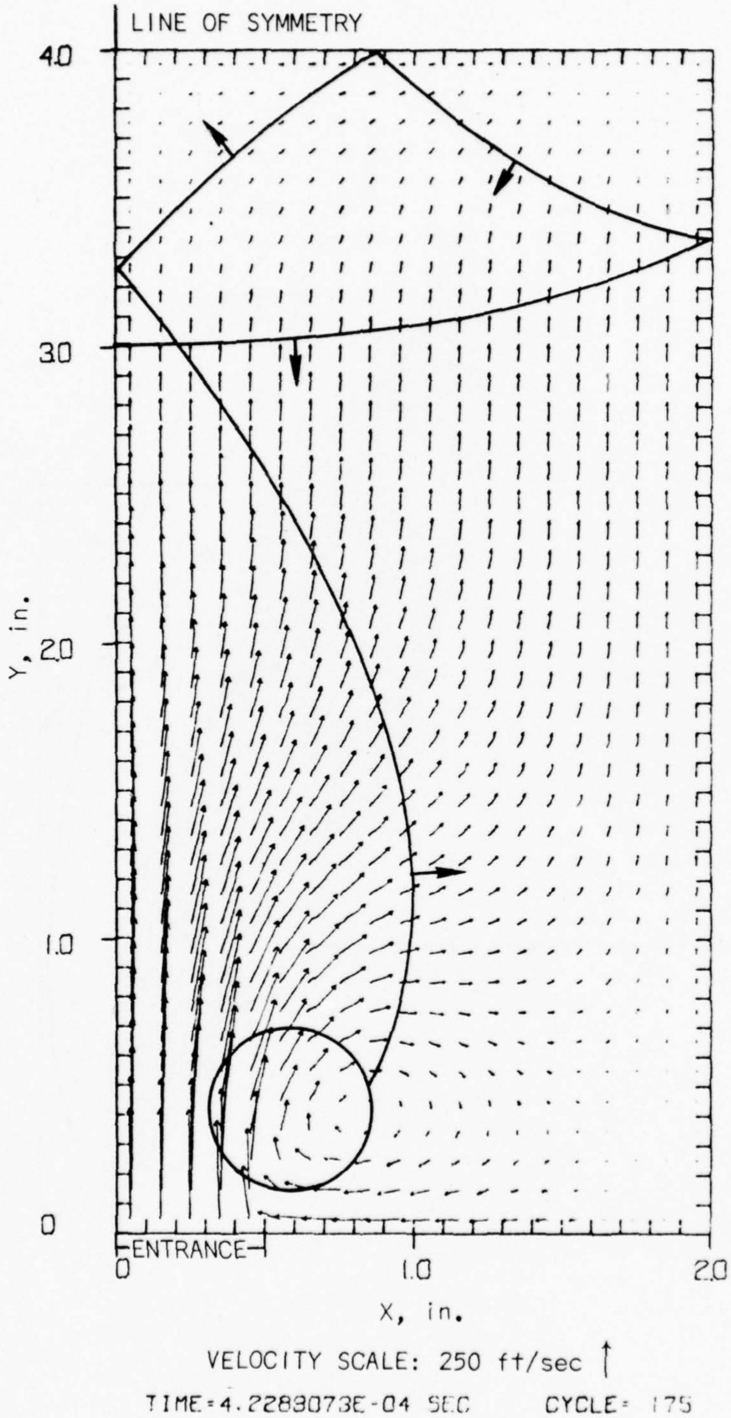

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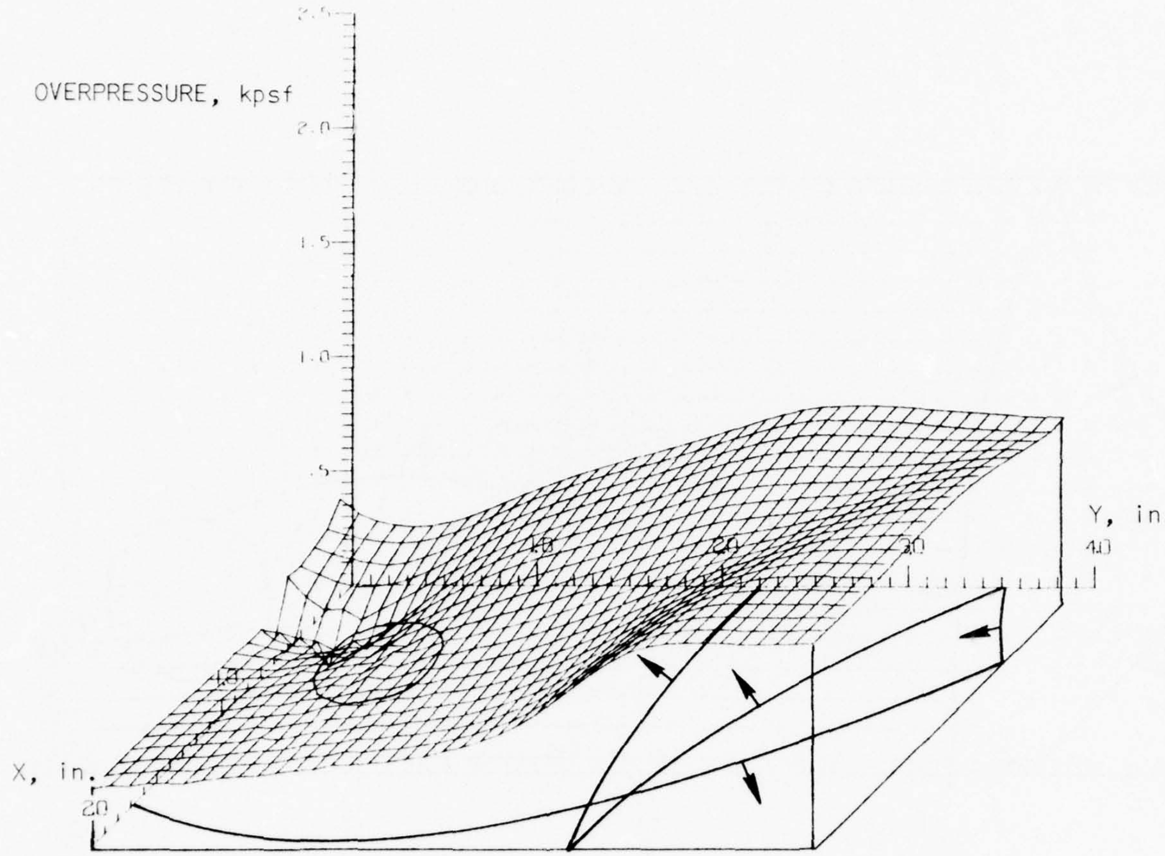

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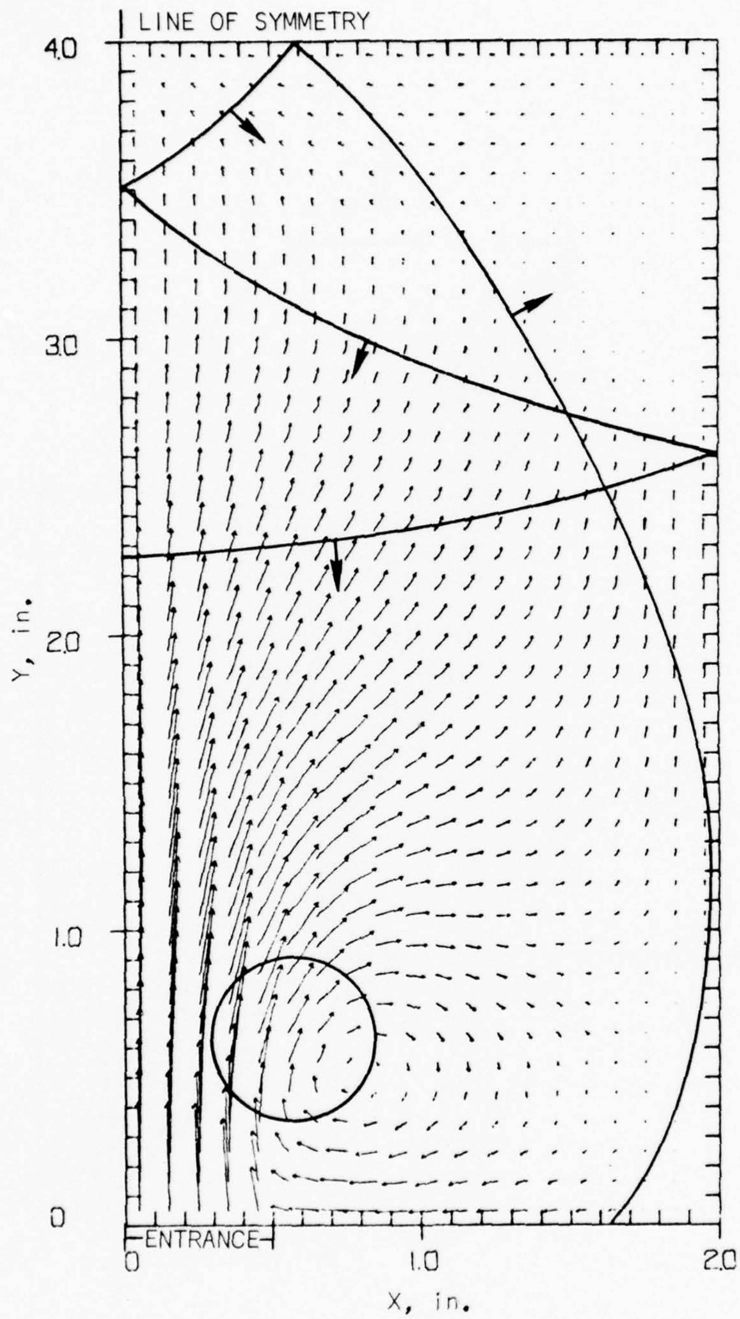

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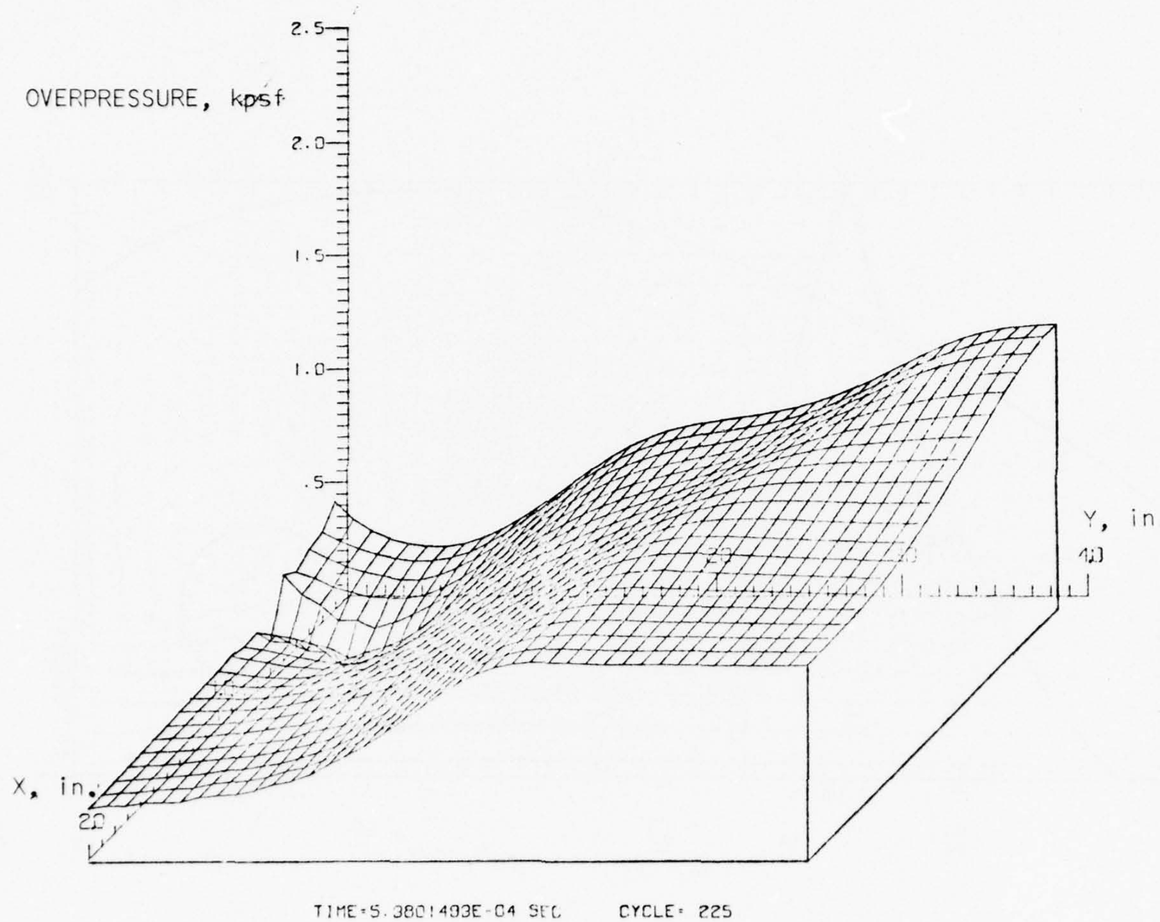

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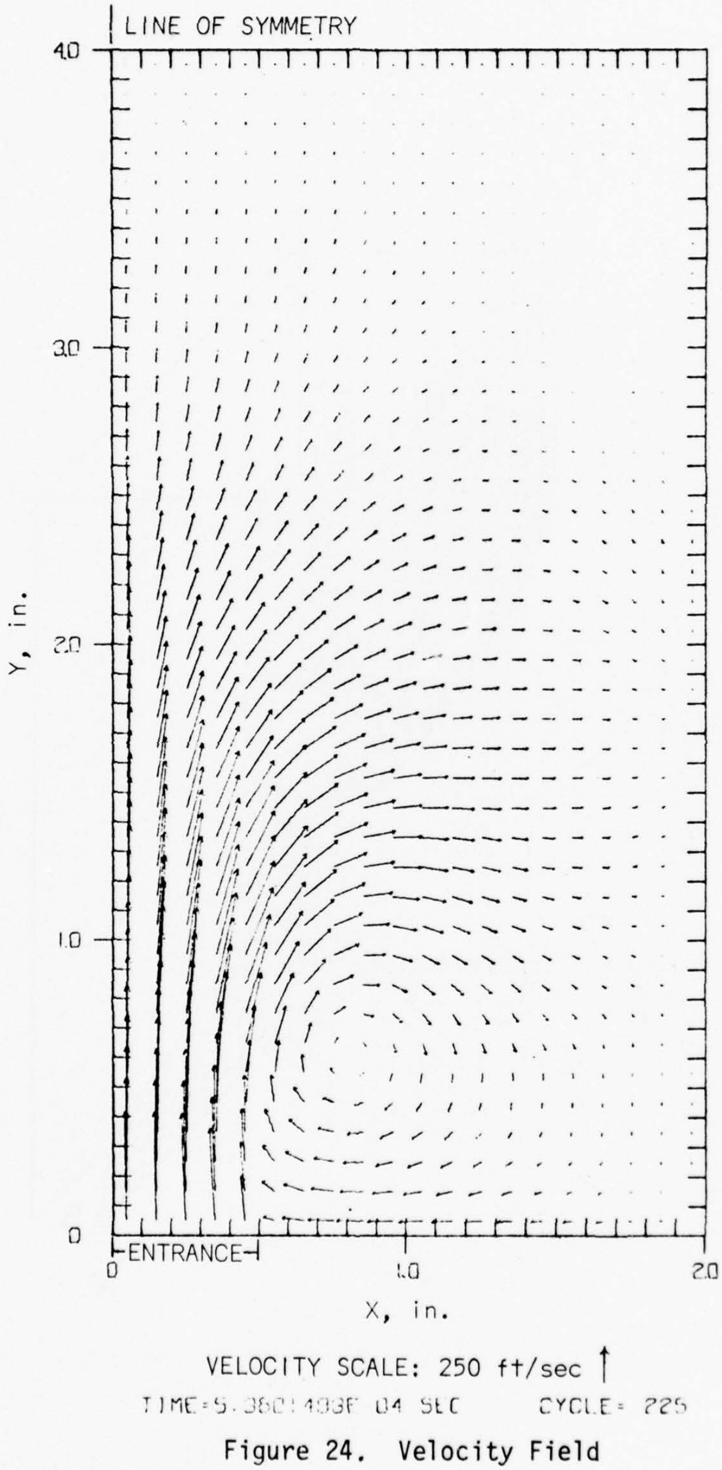

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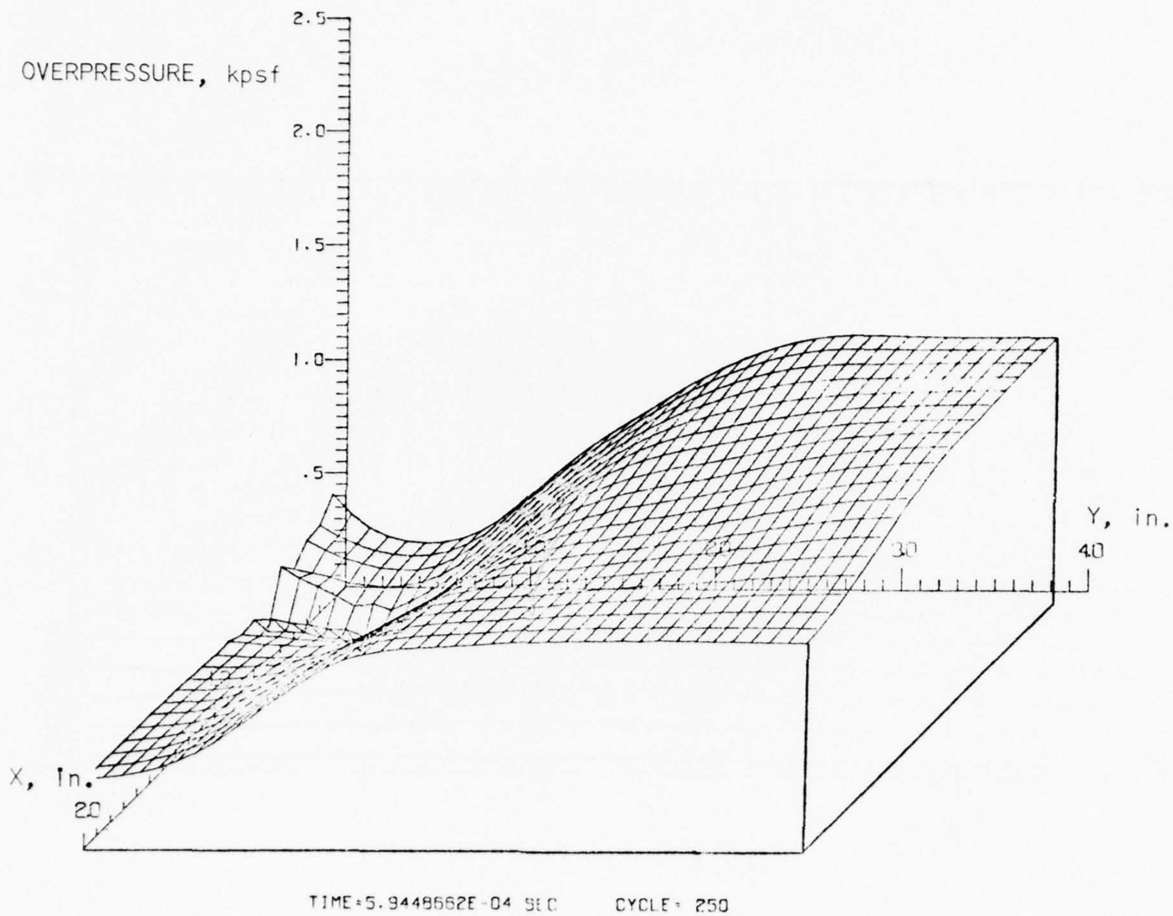

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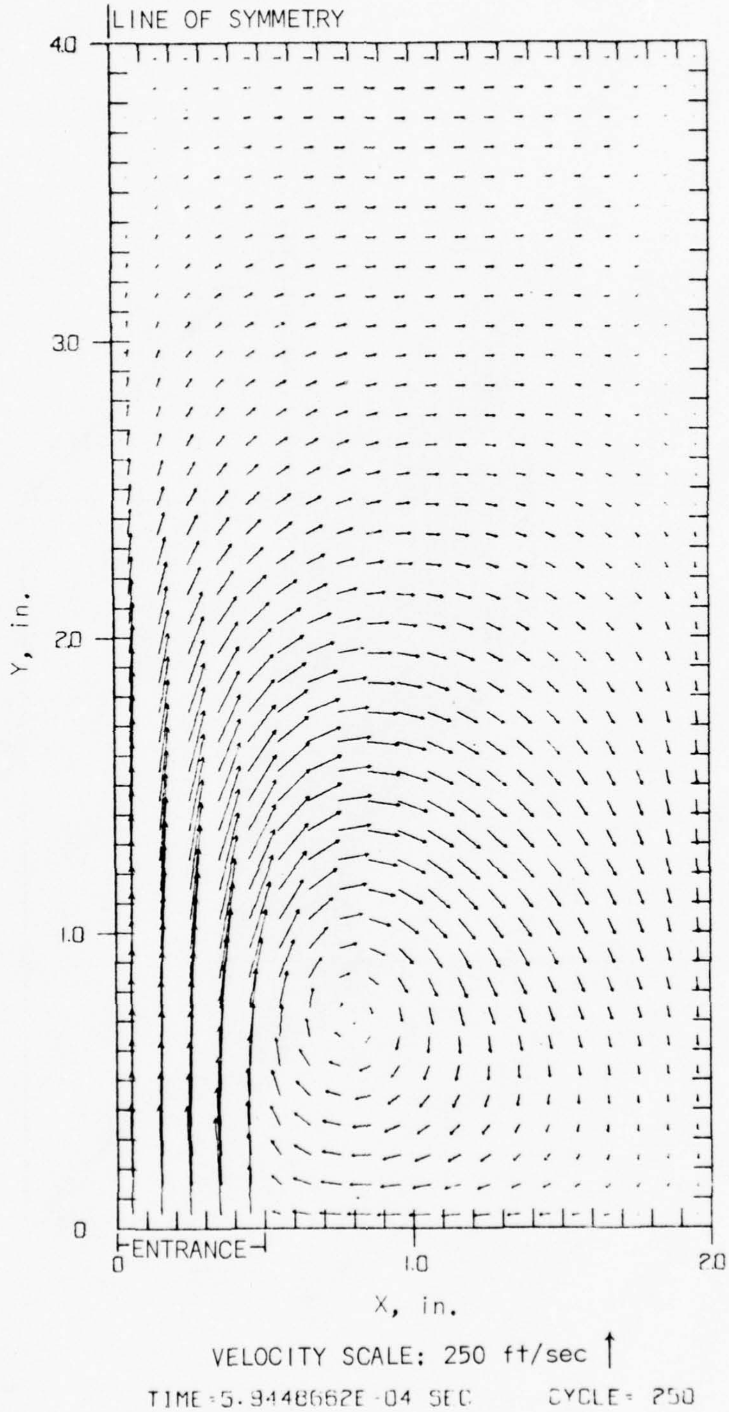

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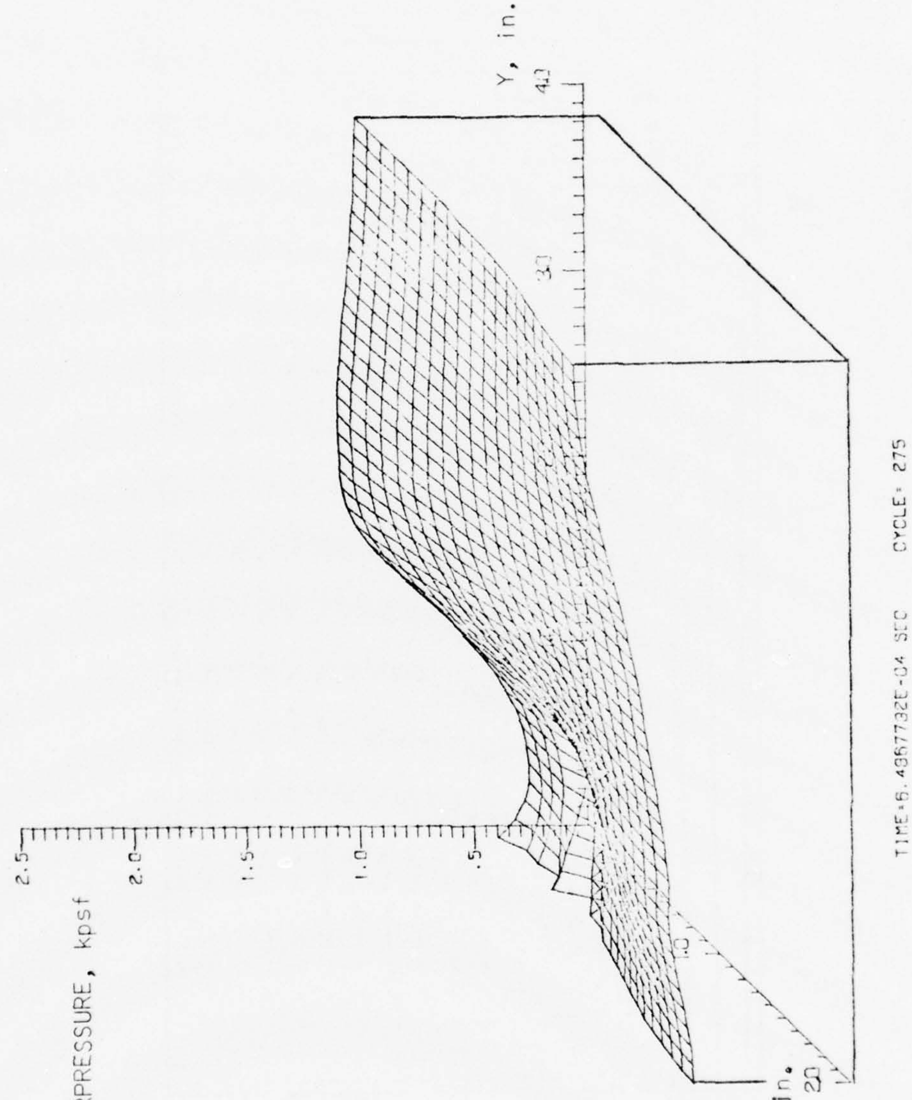

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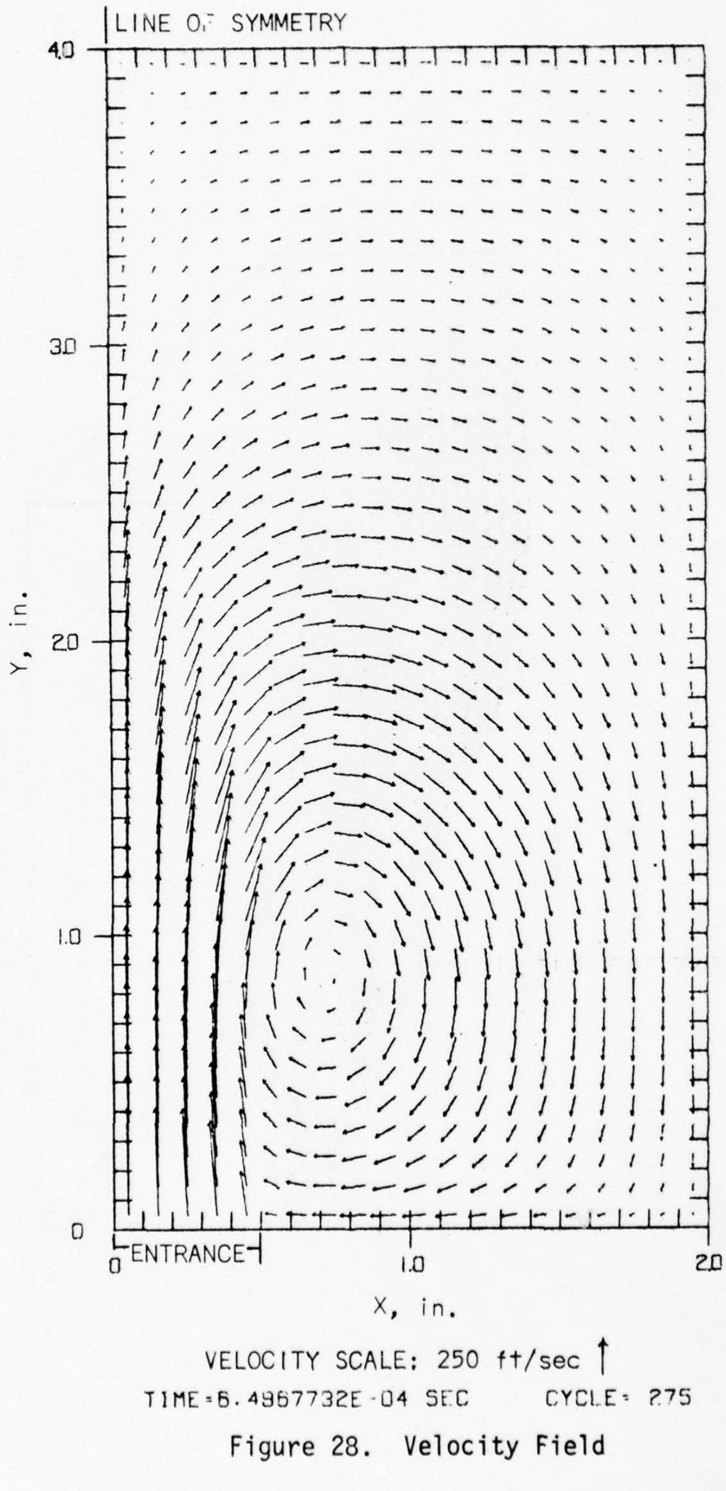

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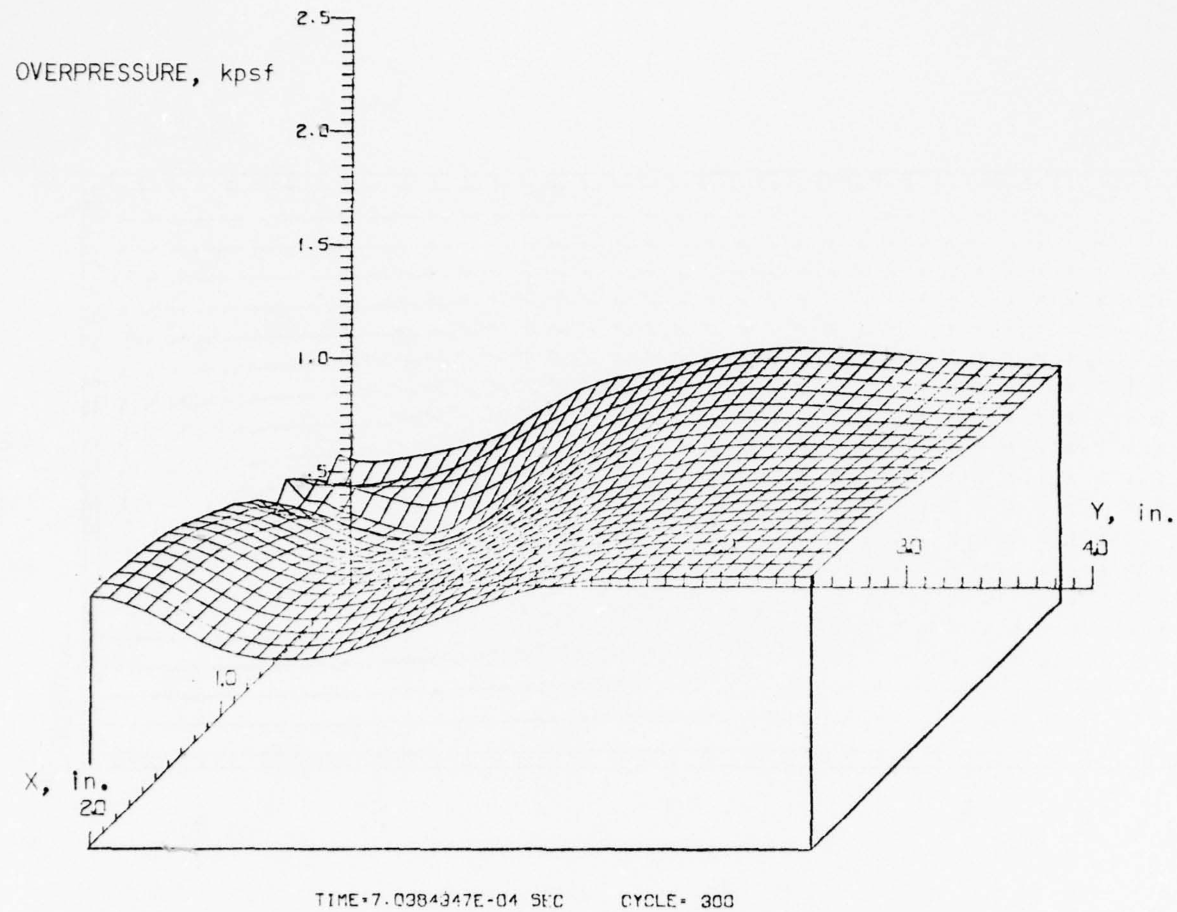

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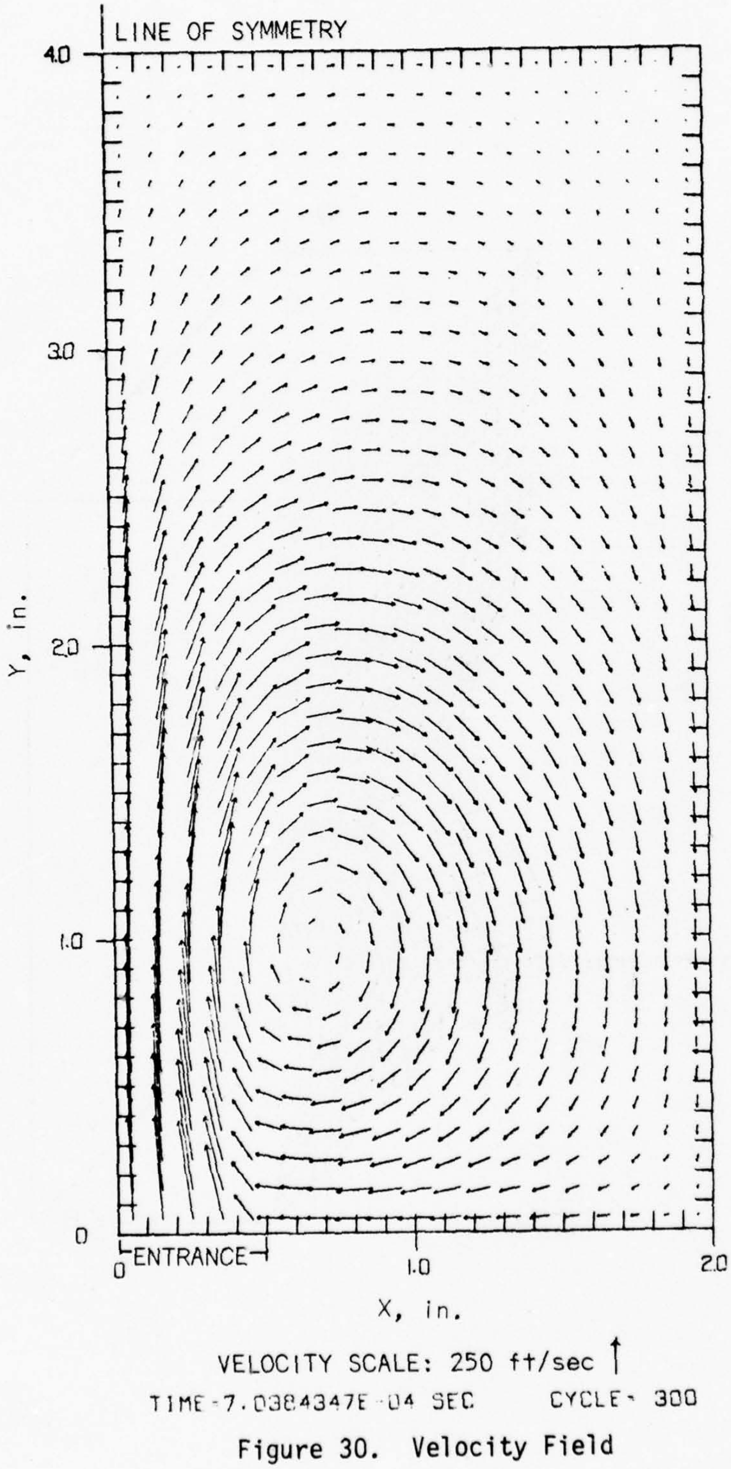

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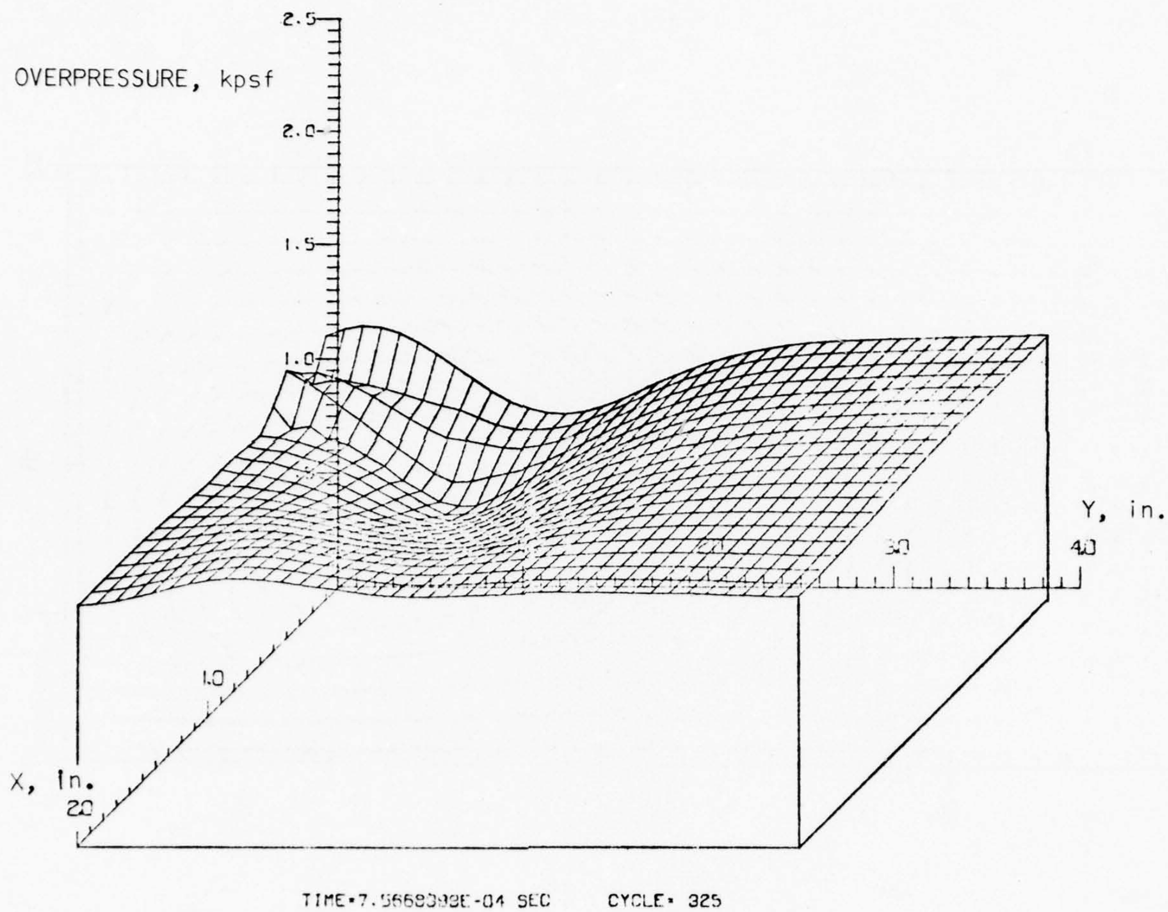
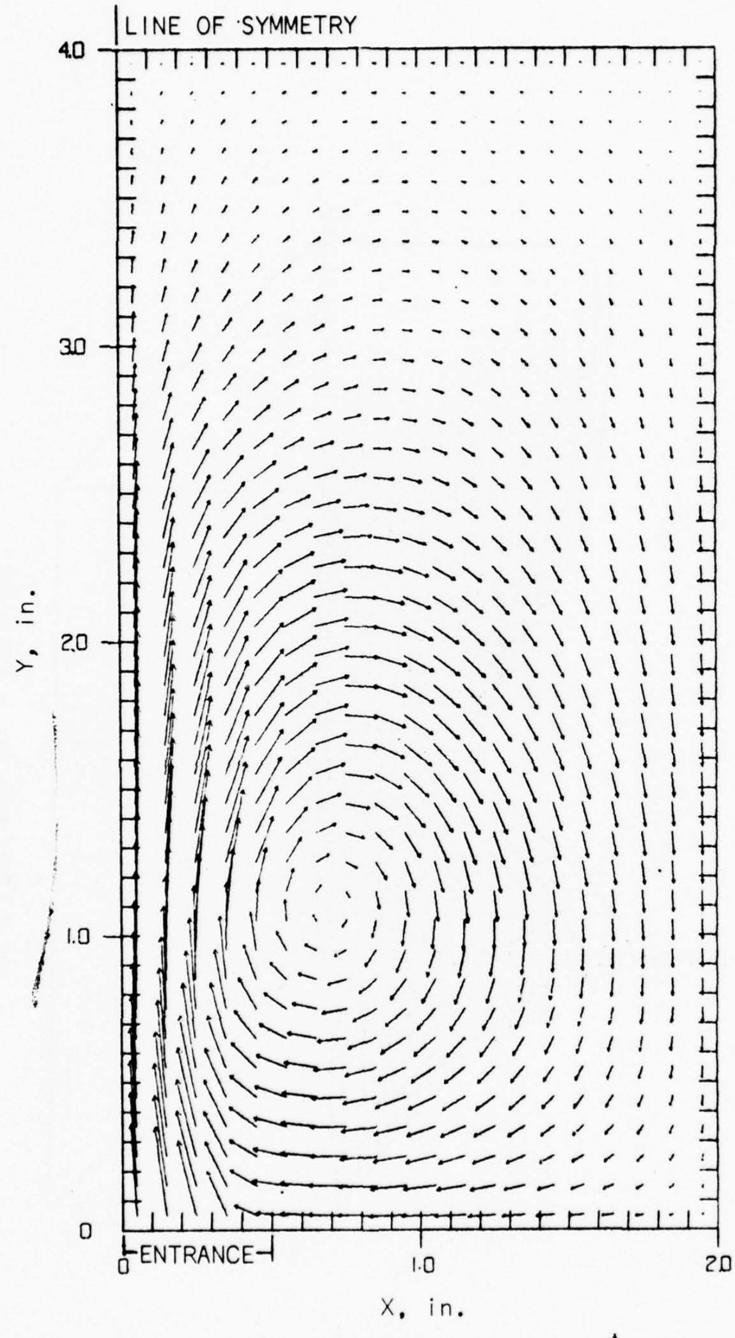


Figure 31. Pressure Field



VELOCITY SCALE: 250 ft/sec

TIME=7.5668399E-04 SEC CYCLE= 325

Figure 32. Velocity Field

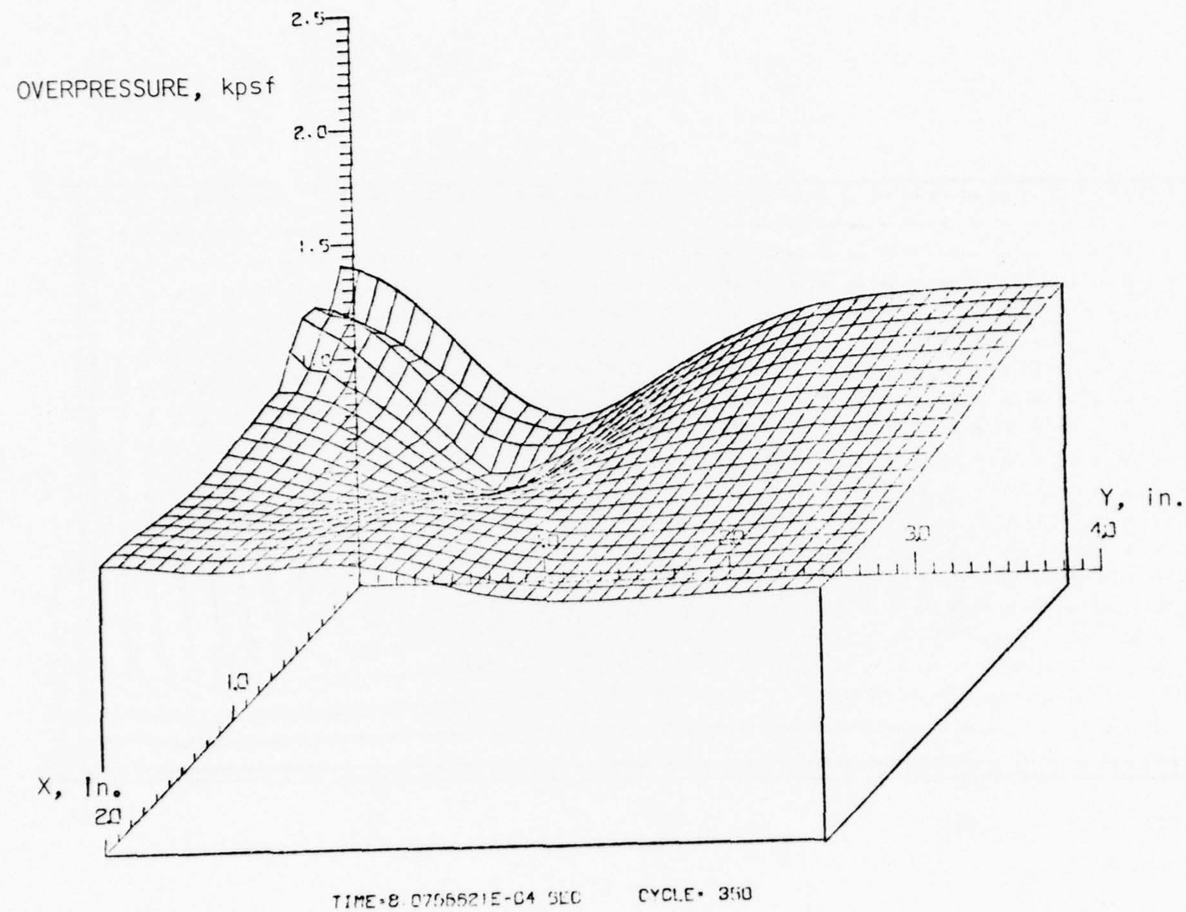


Figure 33. Pressure Field

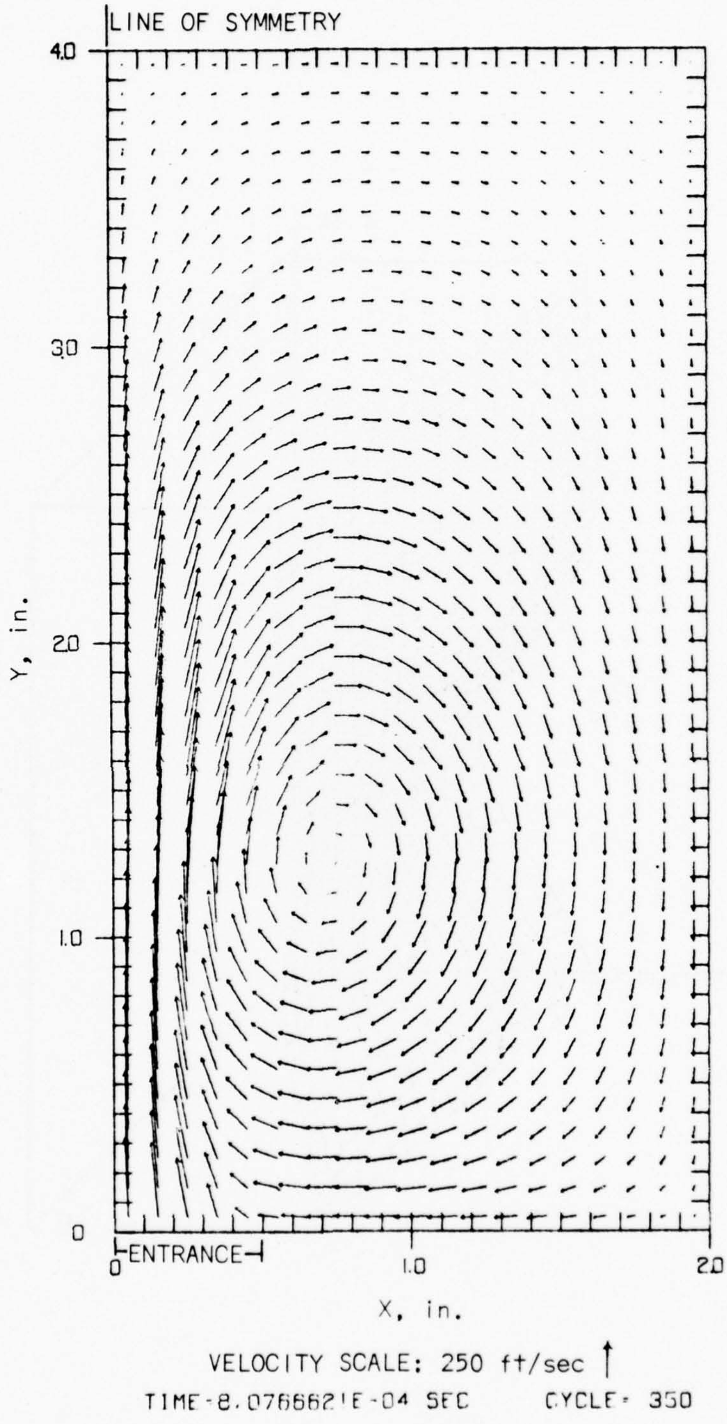


Figure 34. Velocity Field

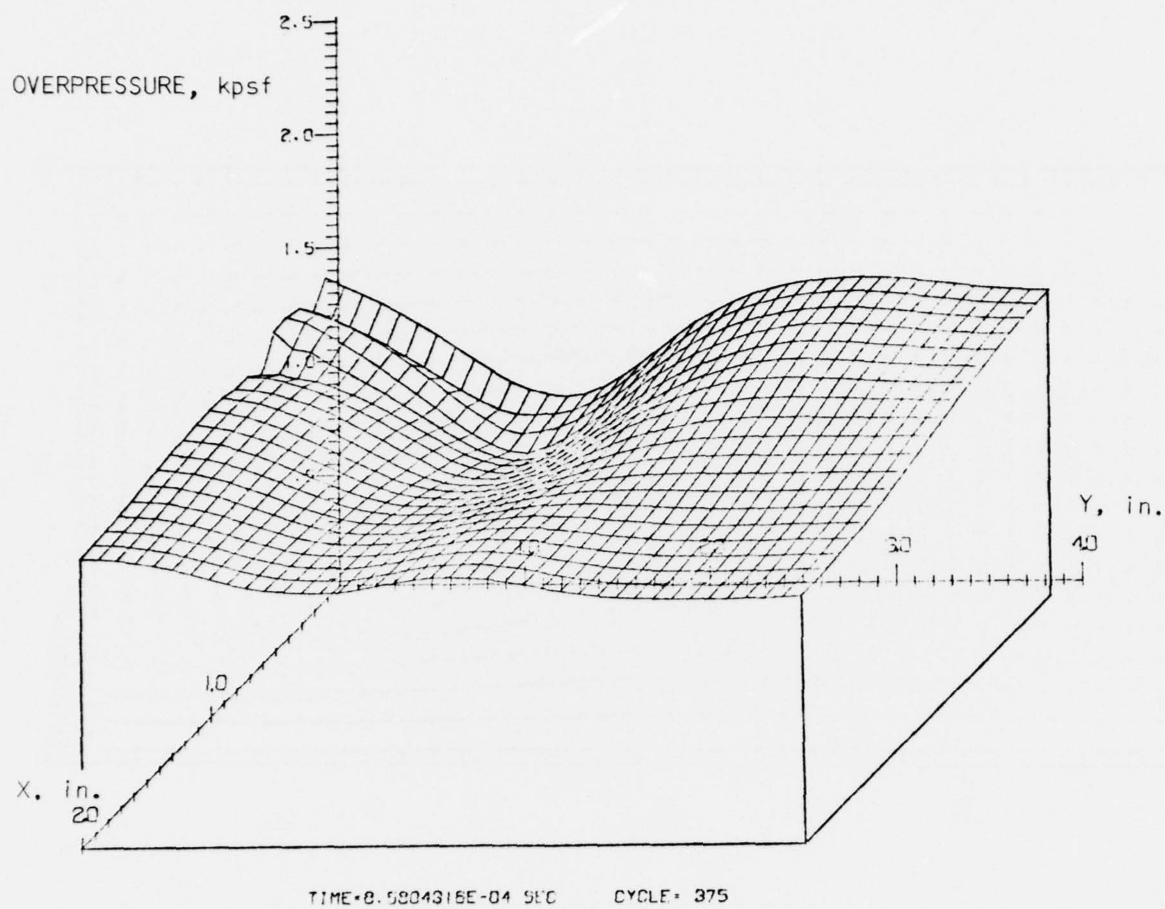


Figure 35. Pressure Field

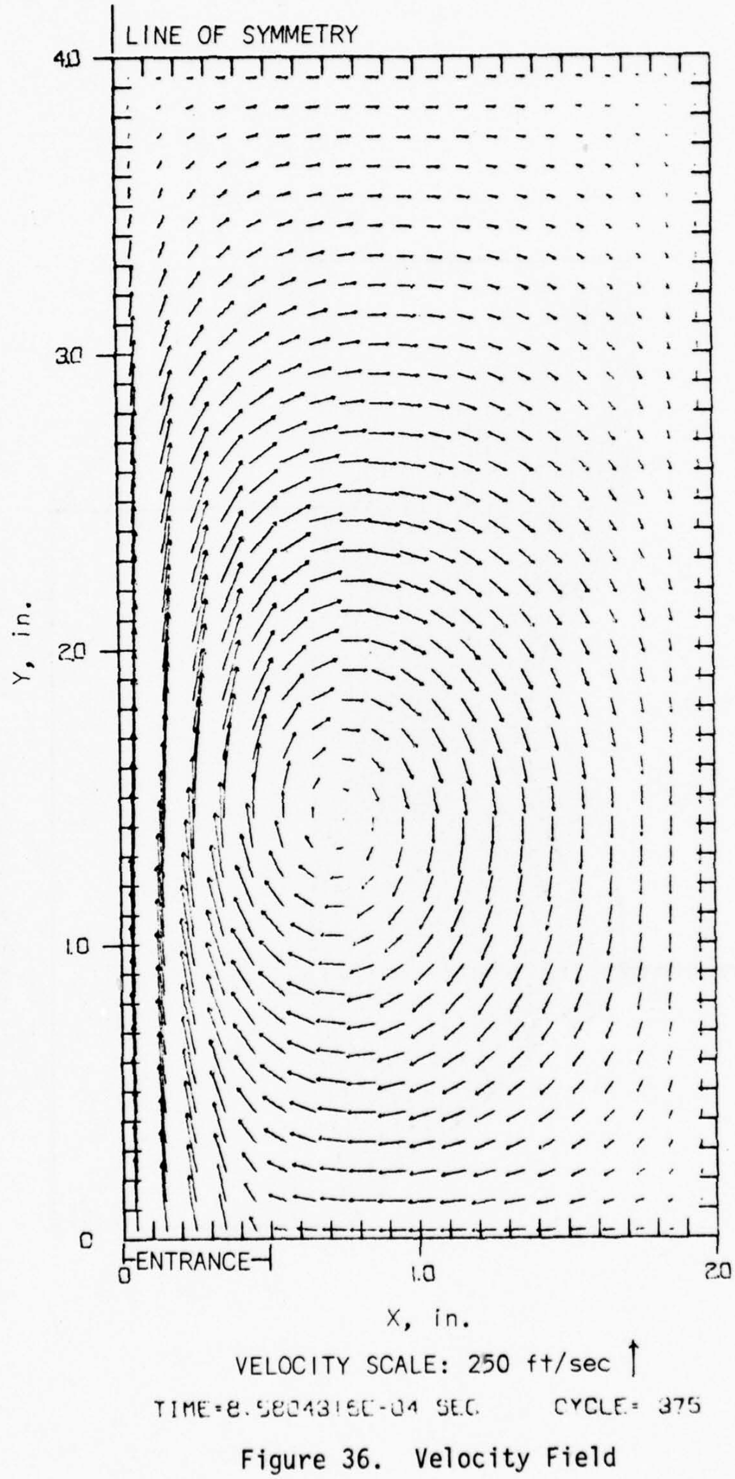
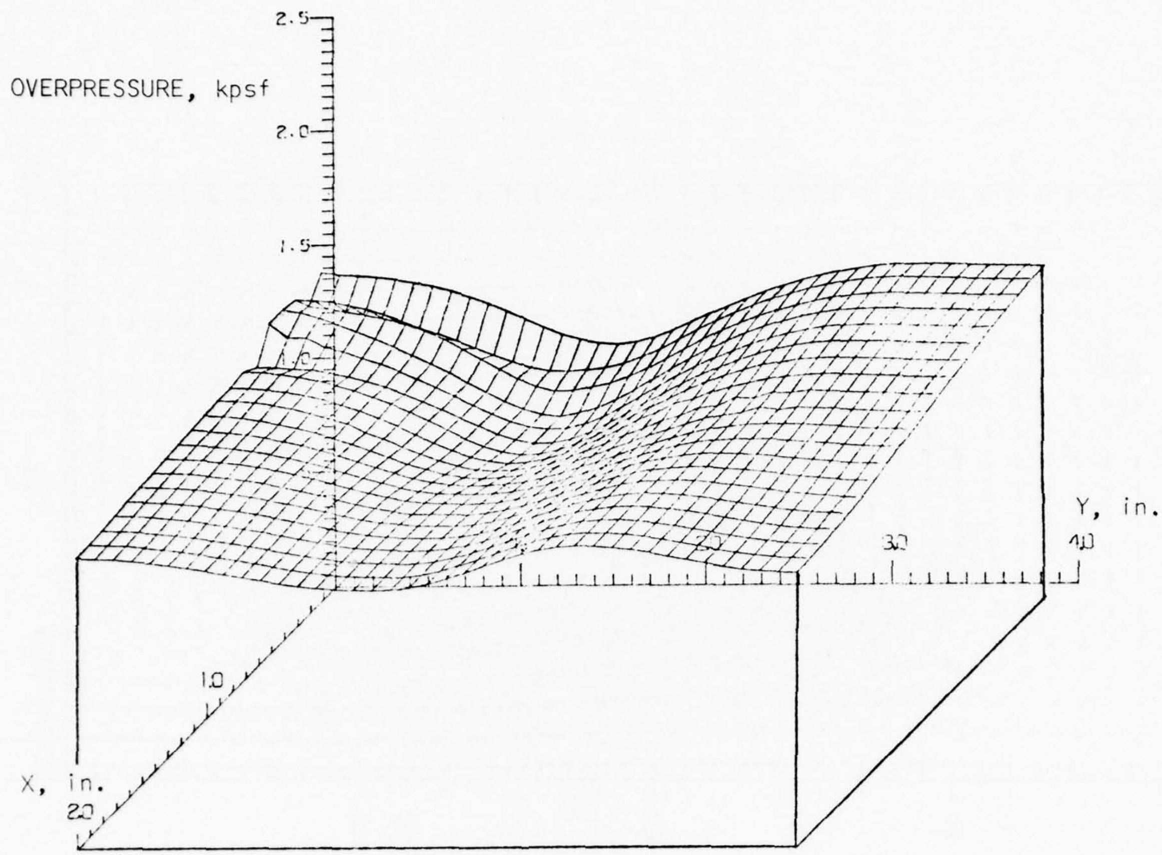


Figure 36. Velocity Field



TIME=0.08559098E-04 SEC   CYCLE= 400

Figure 37. Pressure Field

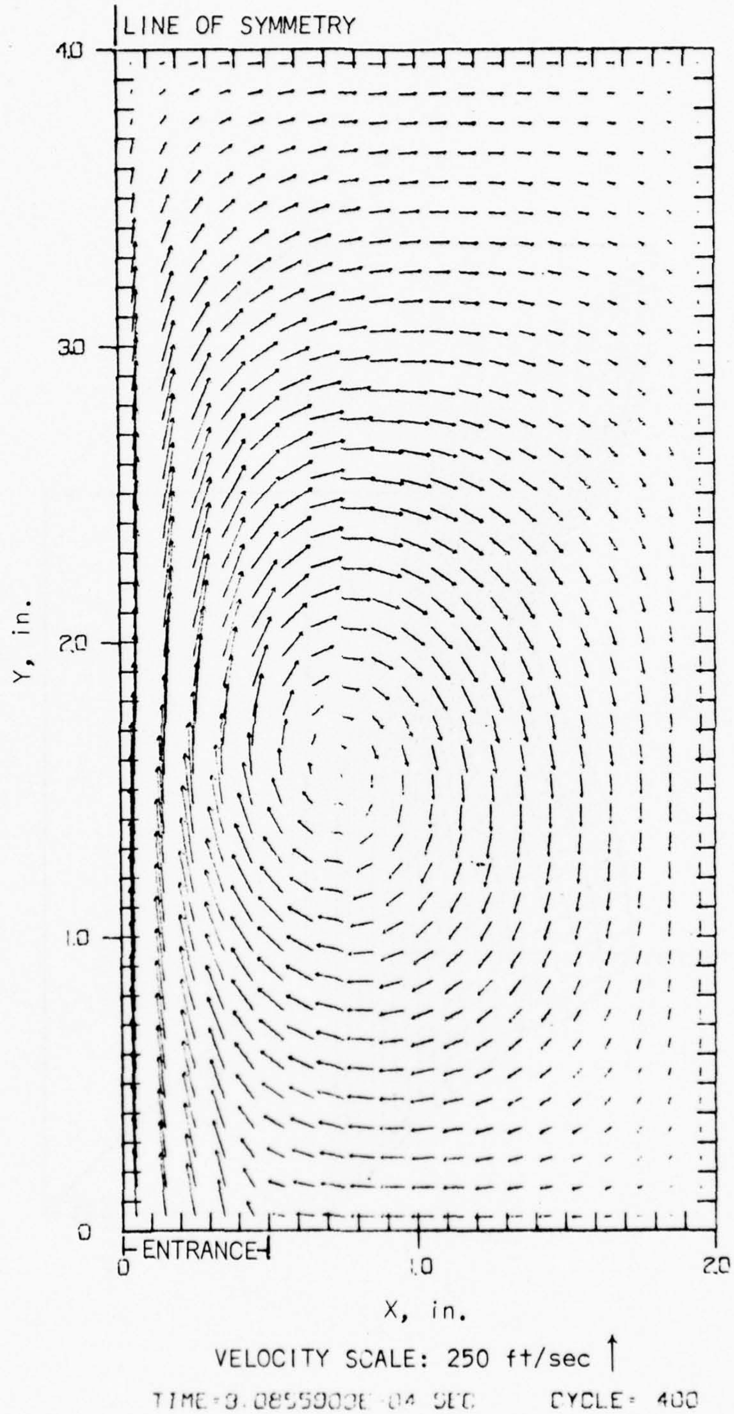


Figure 38. Velocity Field

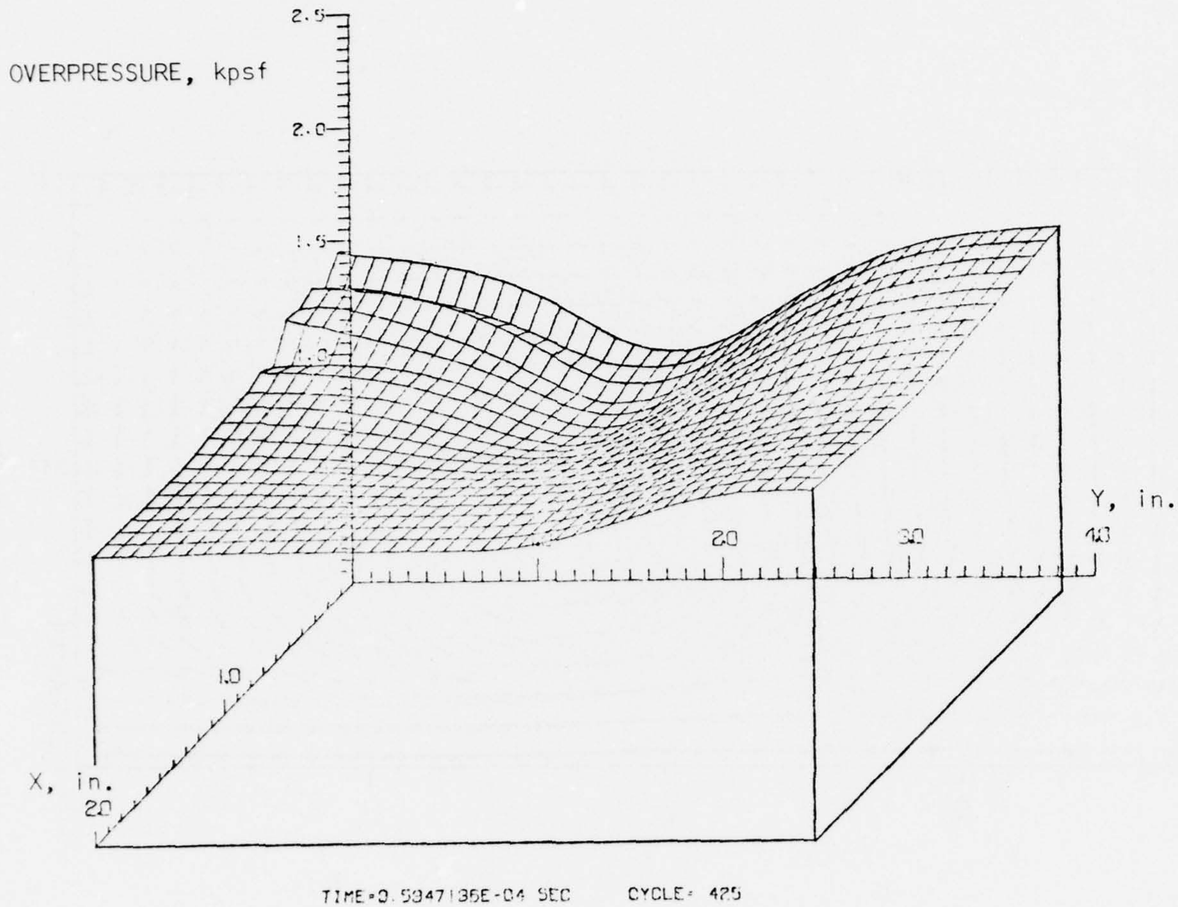
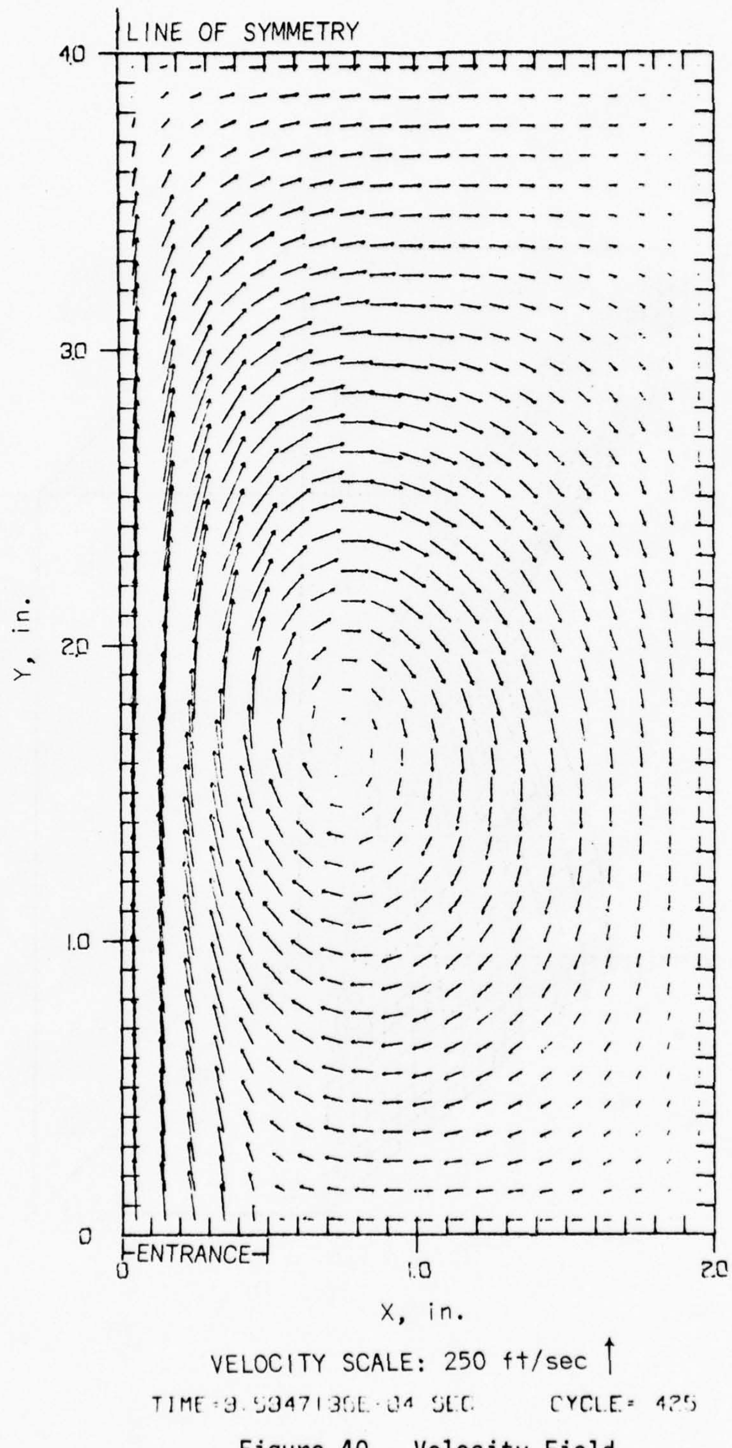


Figure 39. Pressure Field



TIME=9.59471306E-04 SEC CYCLE= 425

Figure 40. Velocity Field

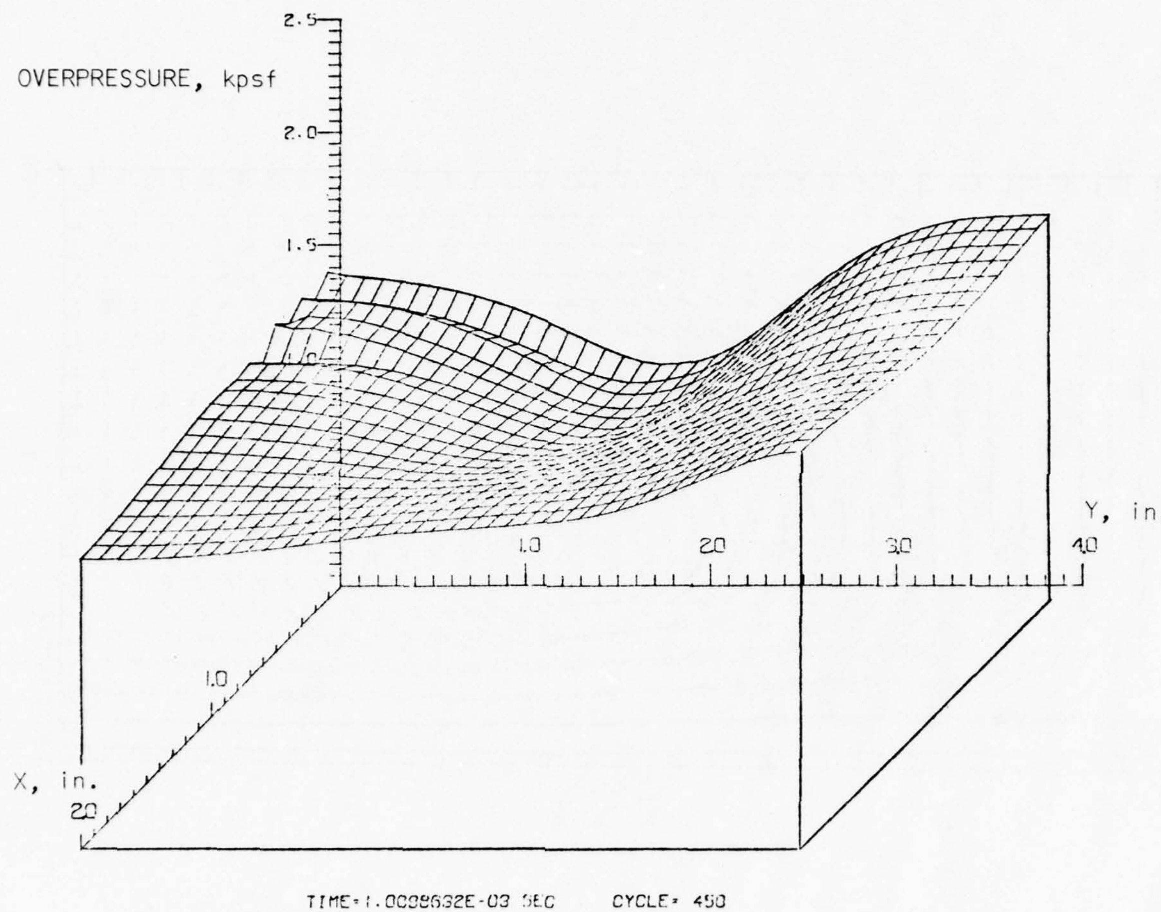
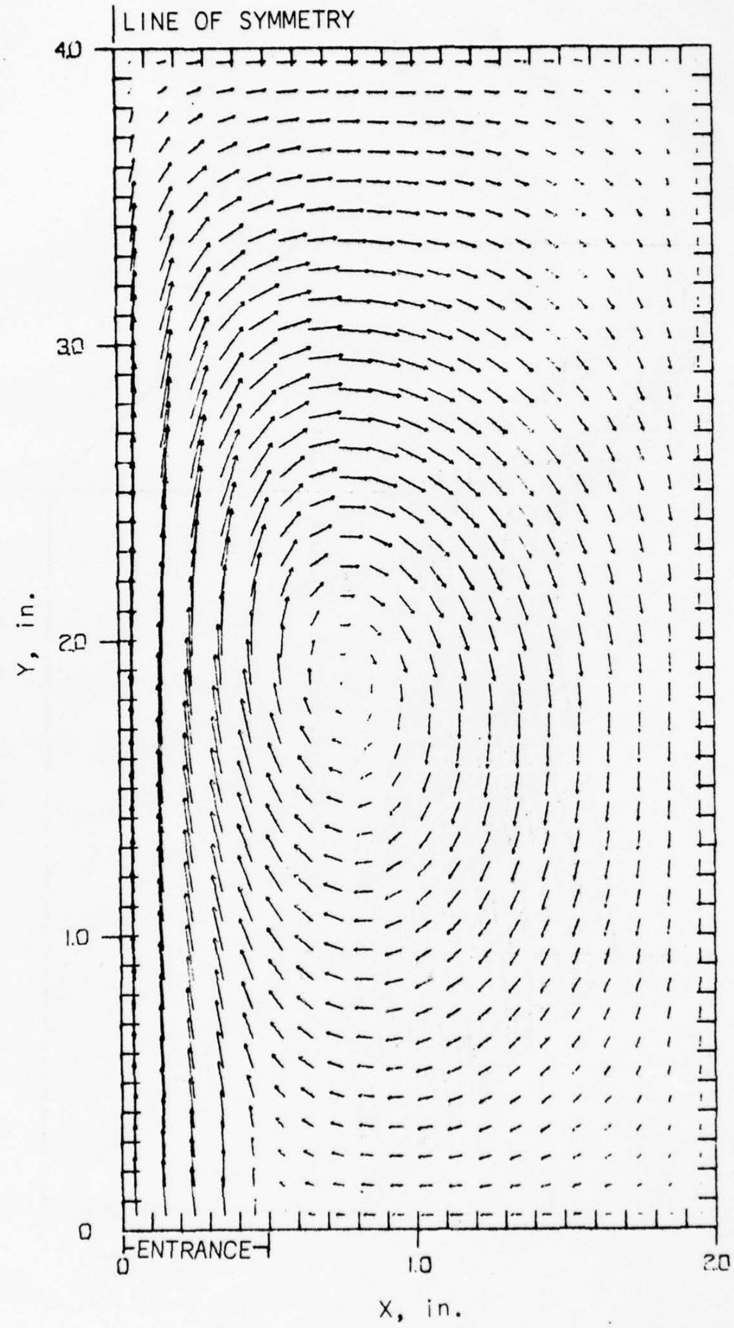


Figure 41. Pressure Field



VELOCITY SCALE: 250 ft/sec ↑

TIME=1.0038632E-03 SEC CYCLE= 450

Figure 42. Velocity Field

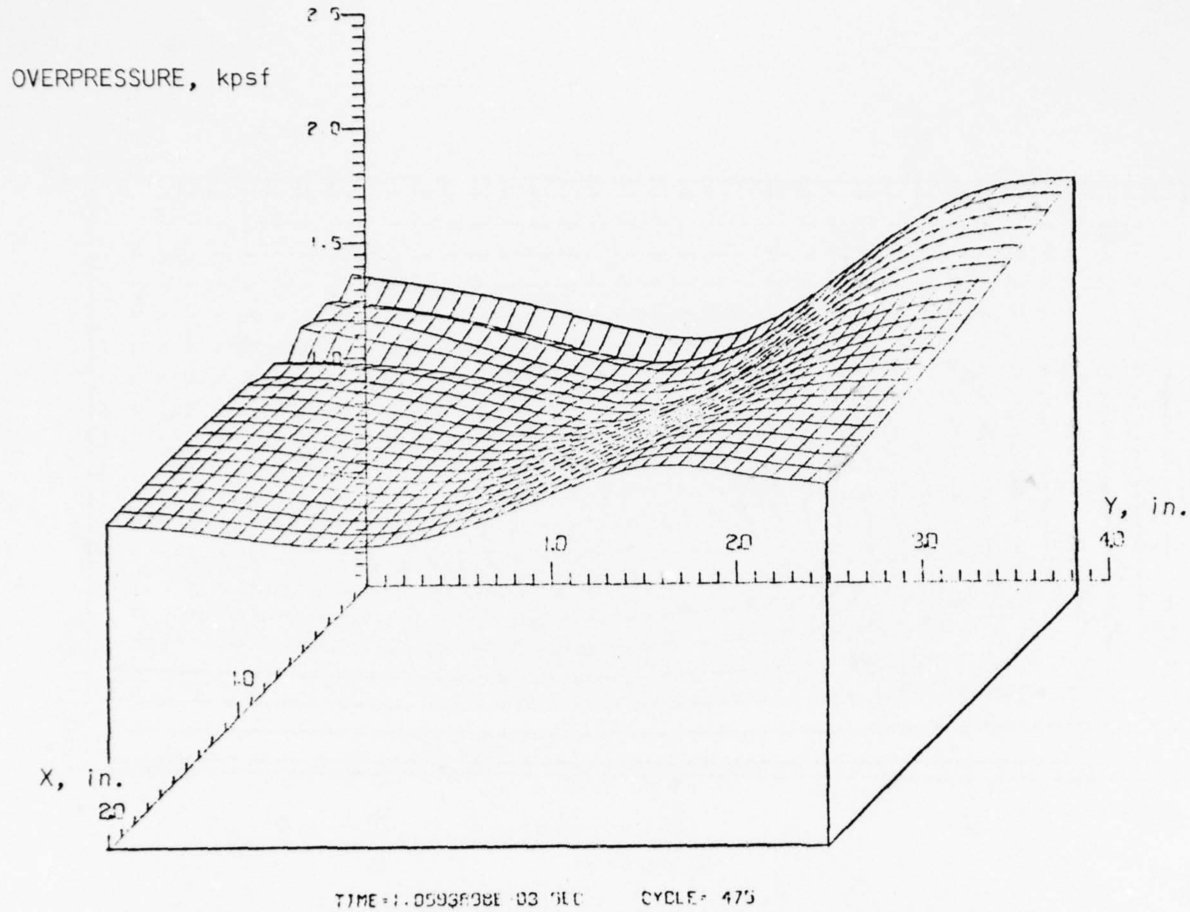


Figure 43. Pressure Field

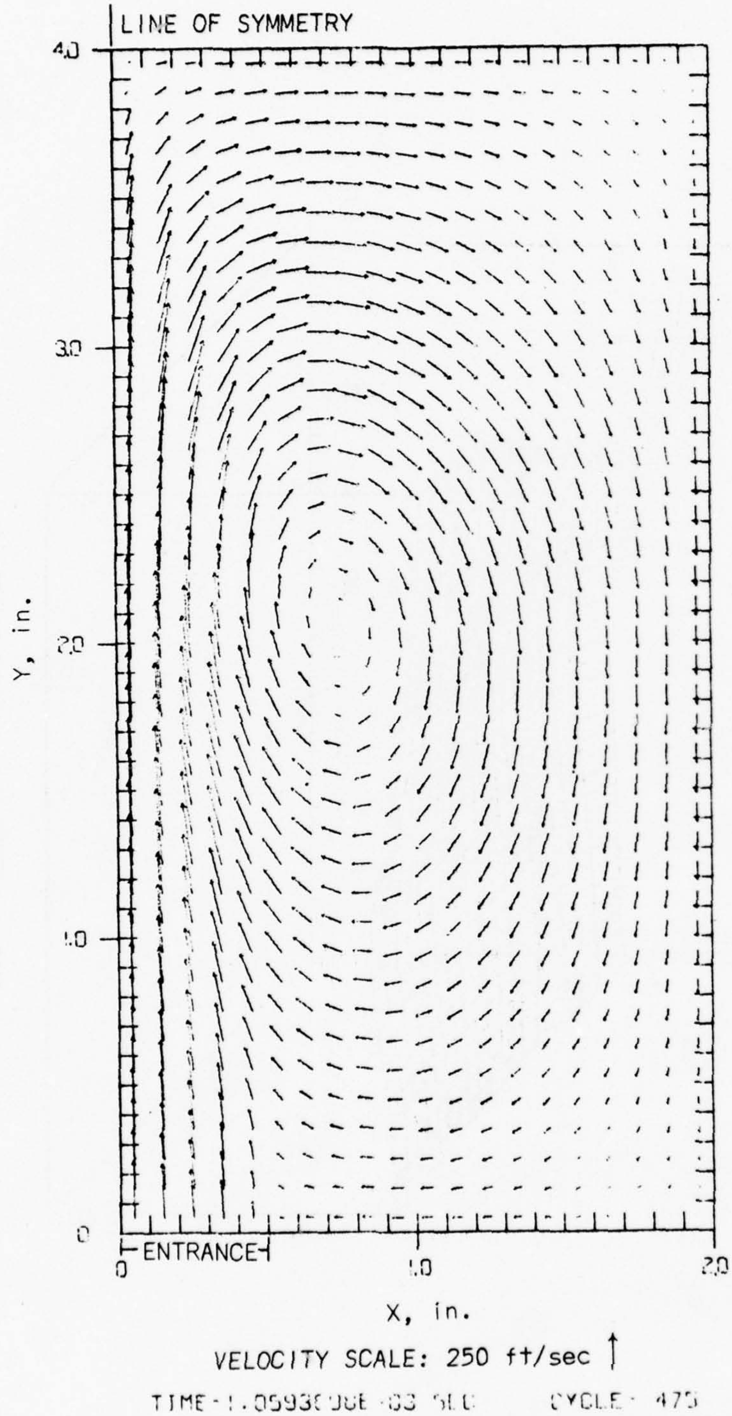


Figure 44. Velocity Field

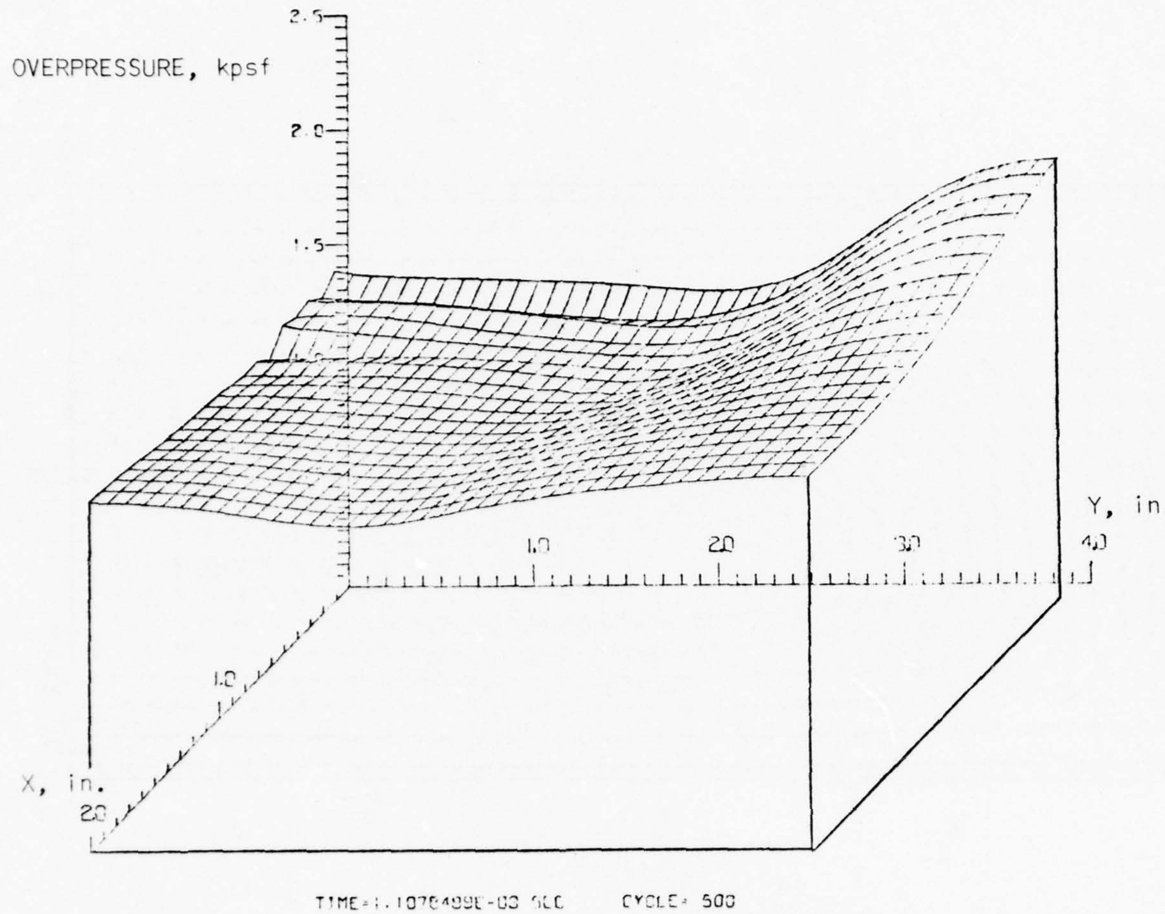


Figure 45. Pressure Field

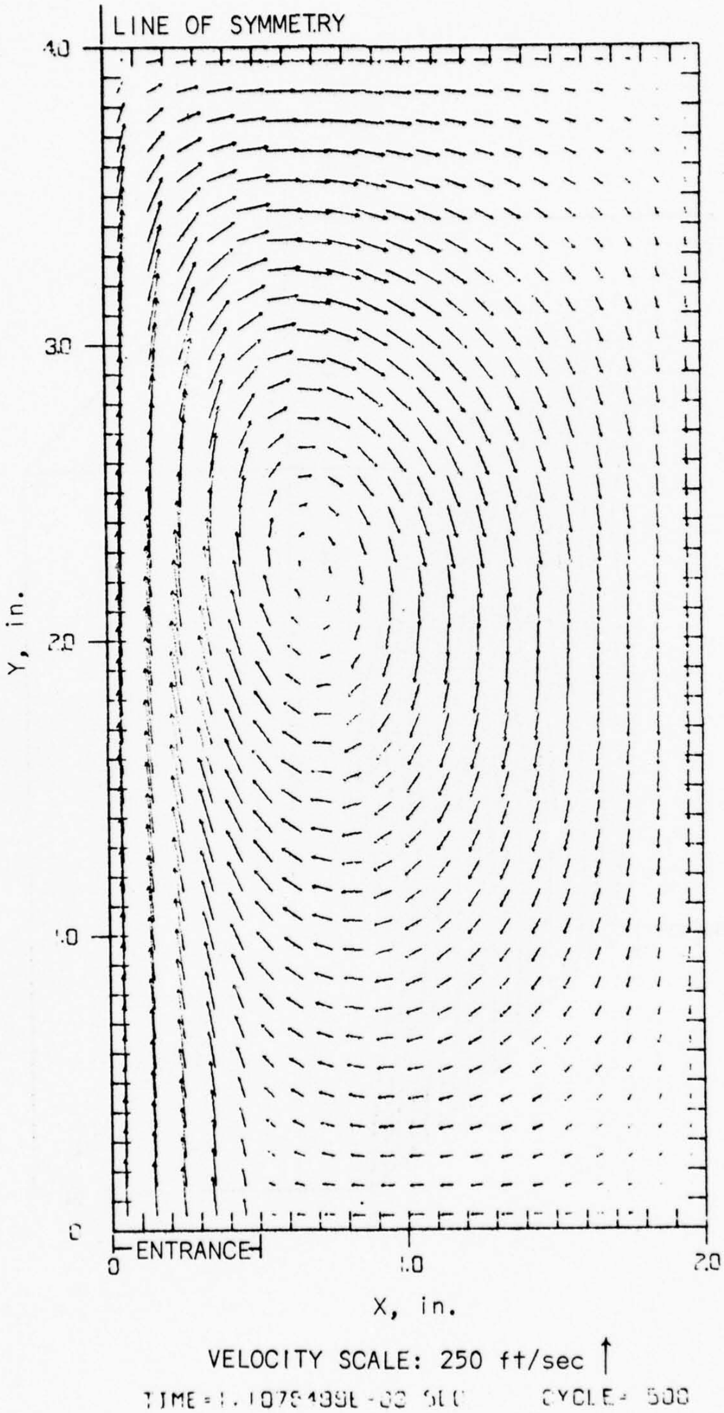


Figure 46. Velocity Field

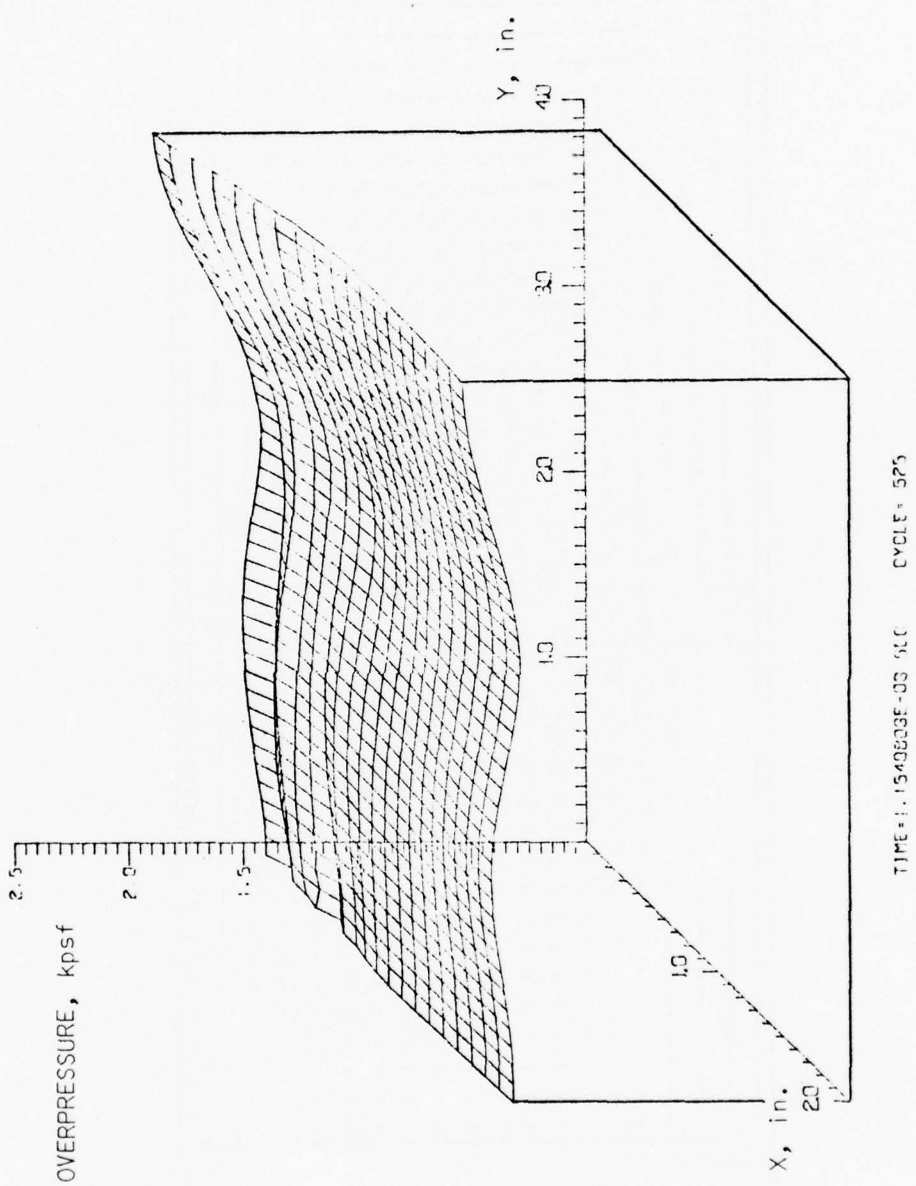
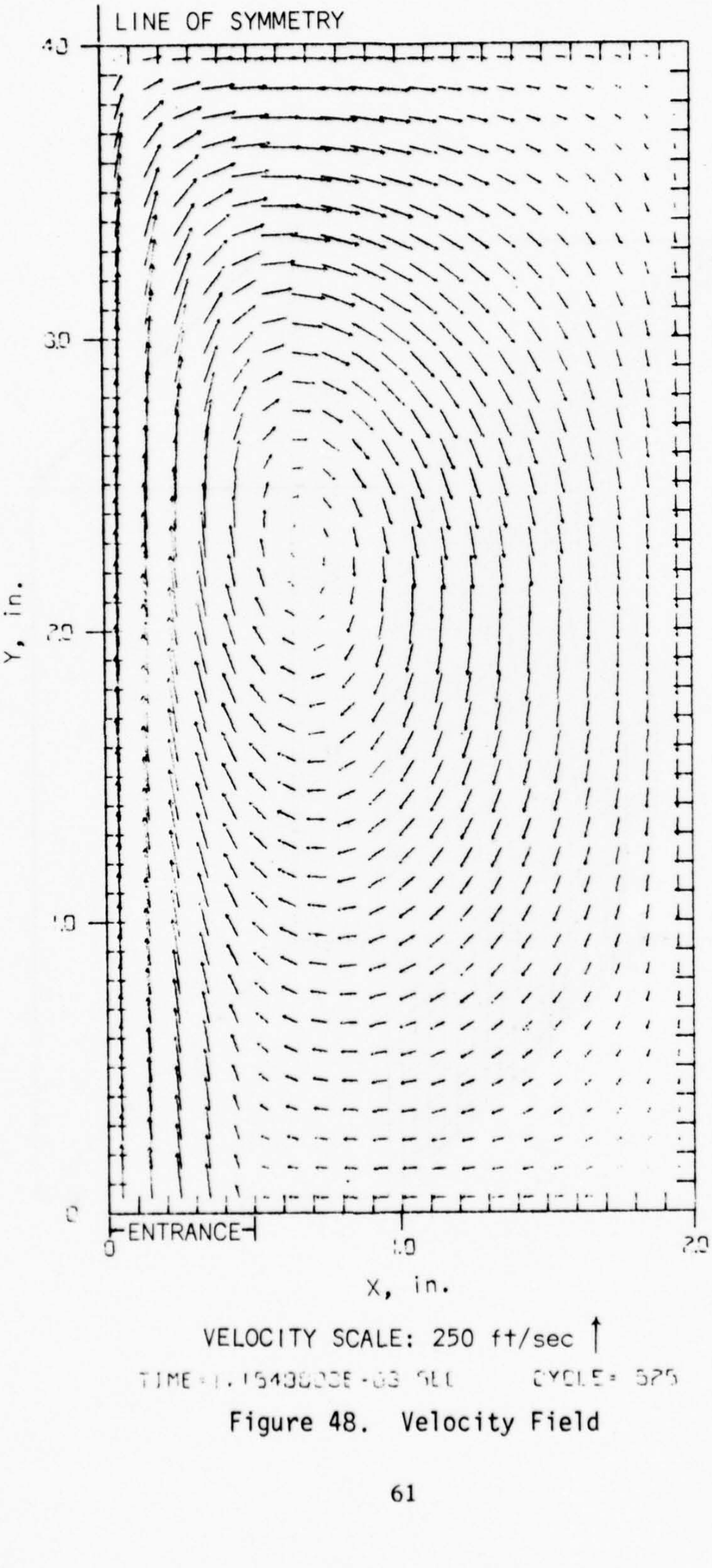


Figure 47. Pressure Field



VELOCITY SCALE: 250 ft/sec ↑

TIME=1.1540000E-03 SEC CYCLE= 525

Figure 48. Velocity Field

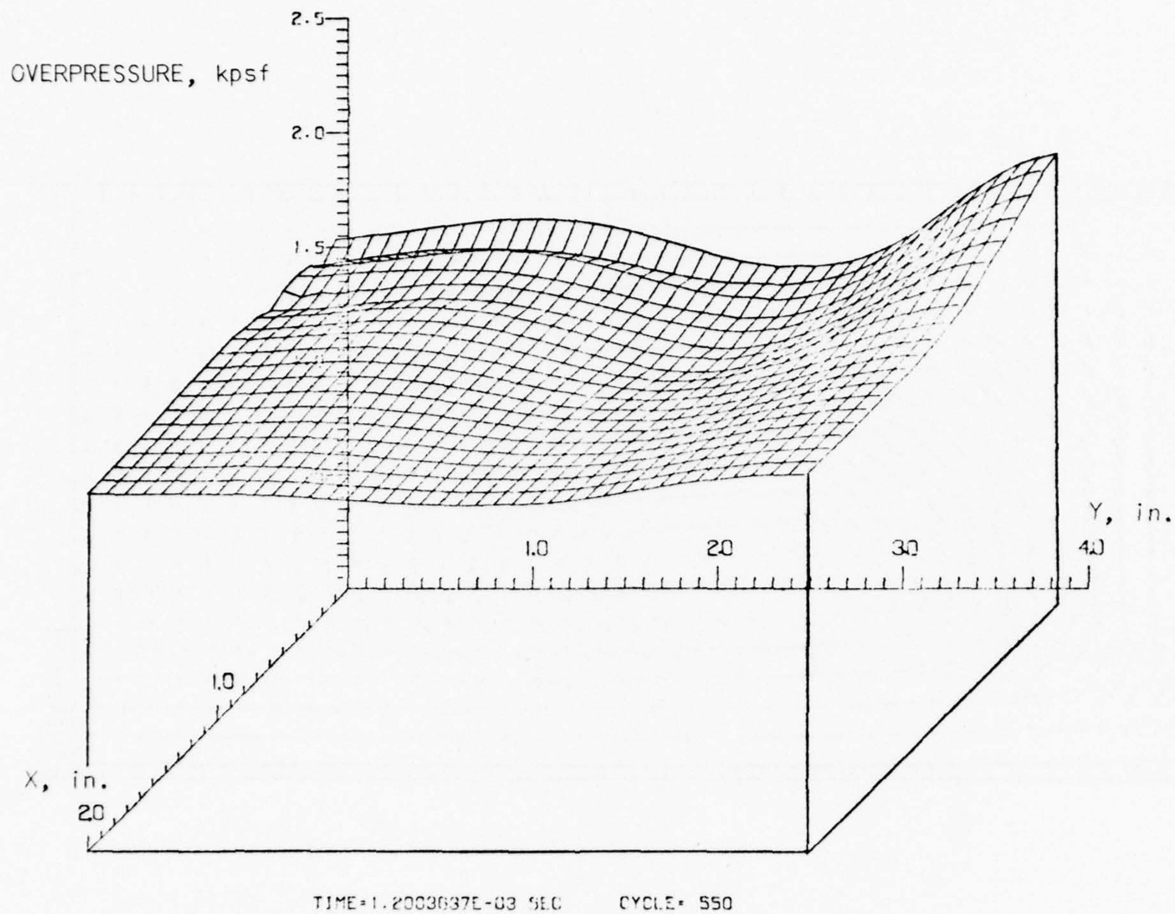
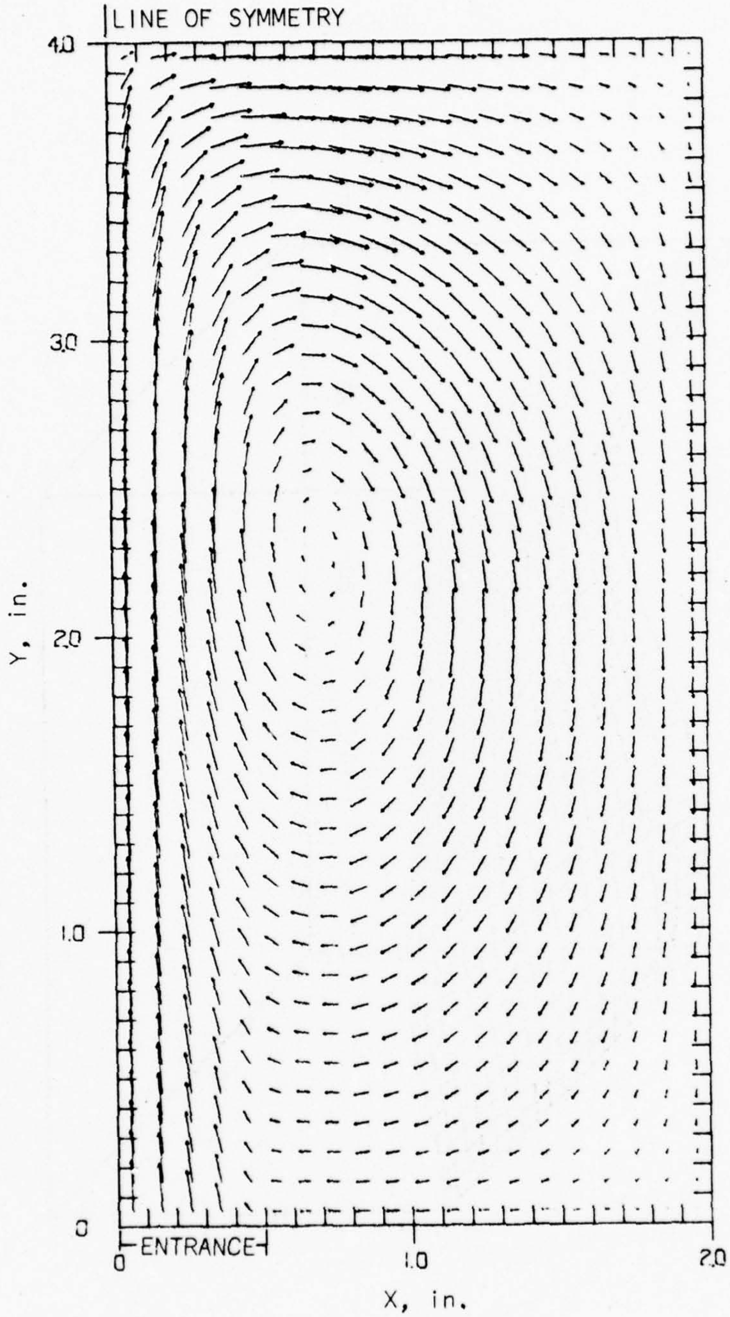


Figure 49. Pressure Field



VELOCITY SCALE: 250 ft/sec ↑

TIME=1.2003687E-03 SEC CYCLE= 550

Figure 50. Velocity Field

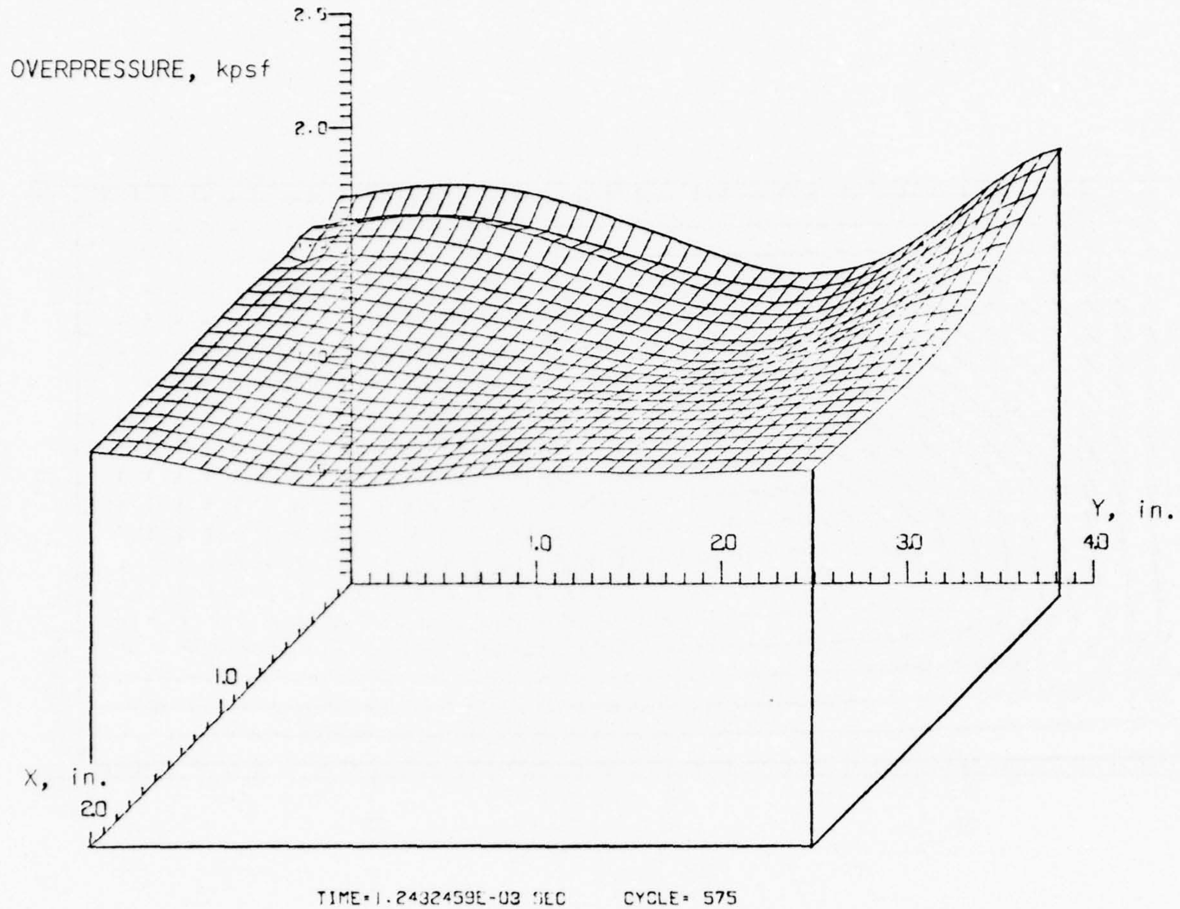


Figure 51. Pressure Field

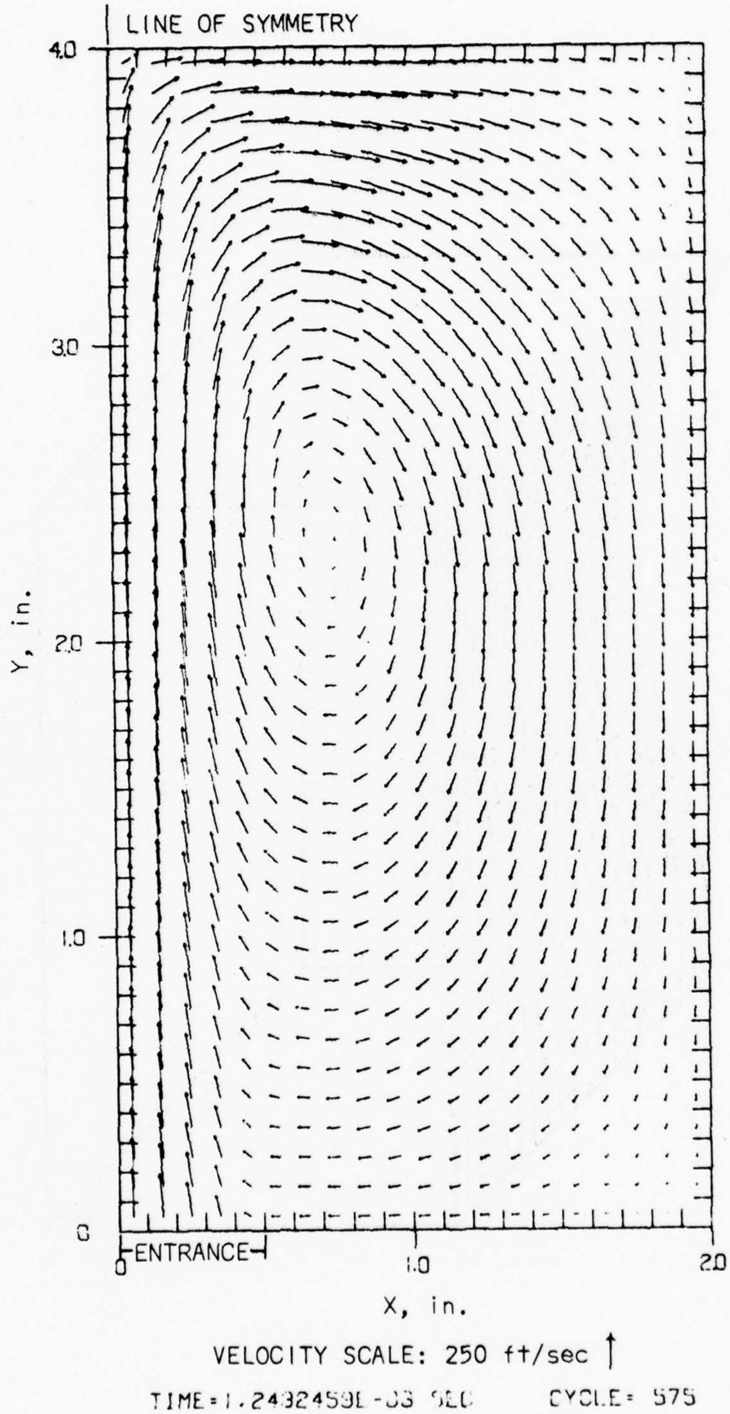


Figure 52. Velocity Field

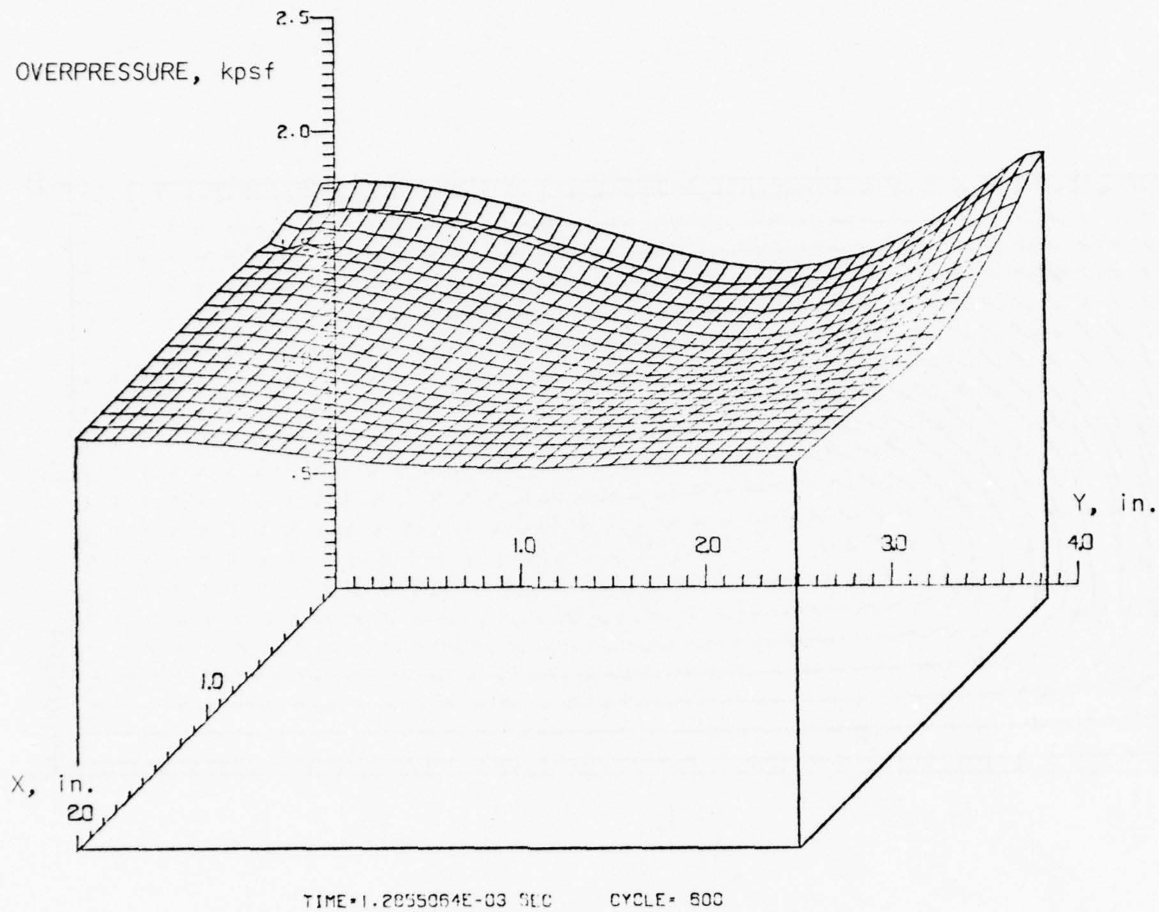


Figure 53. Pressure Field

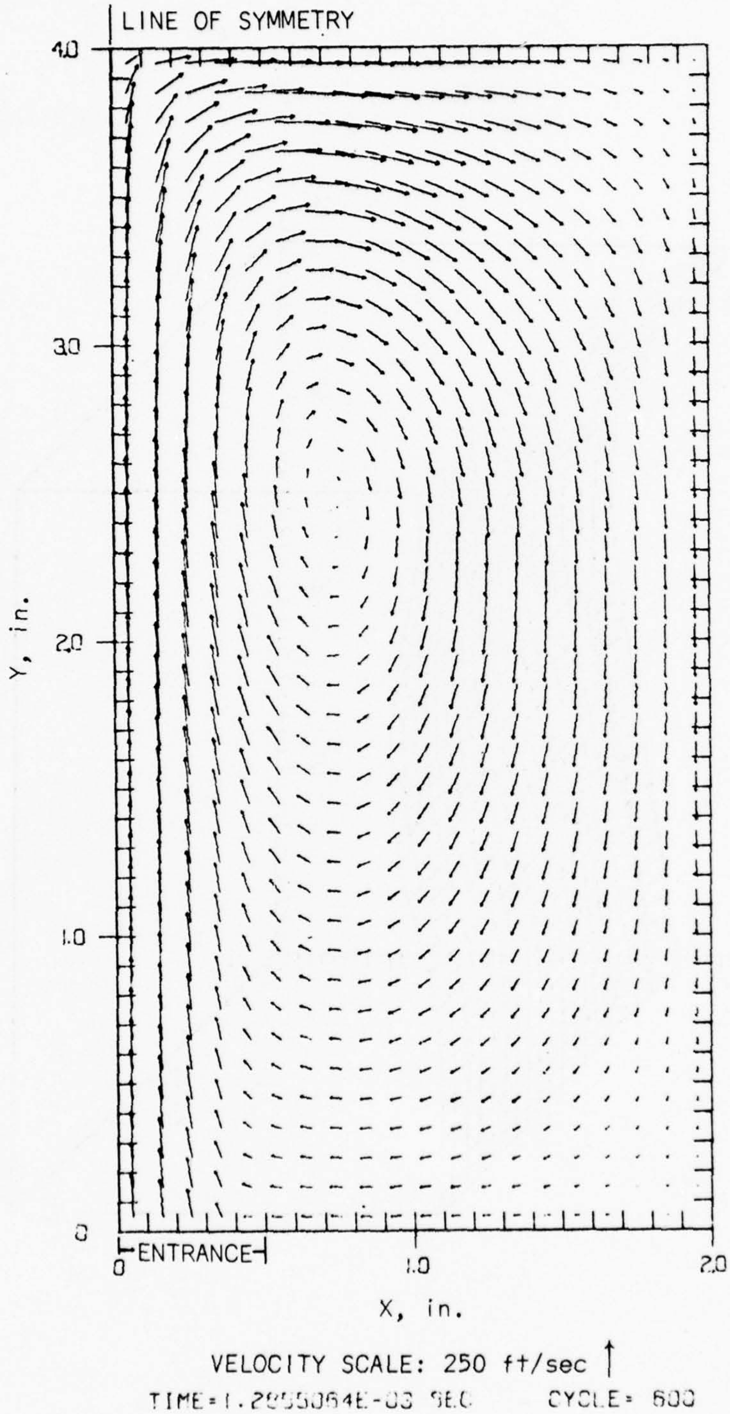


Figure 54. Velocity Field

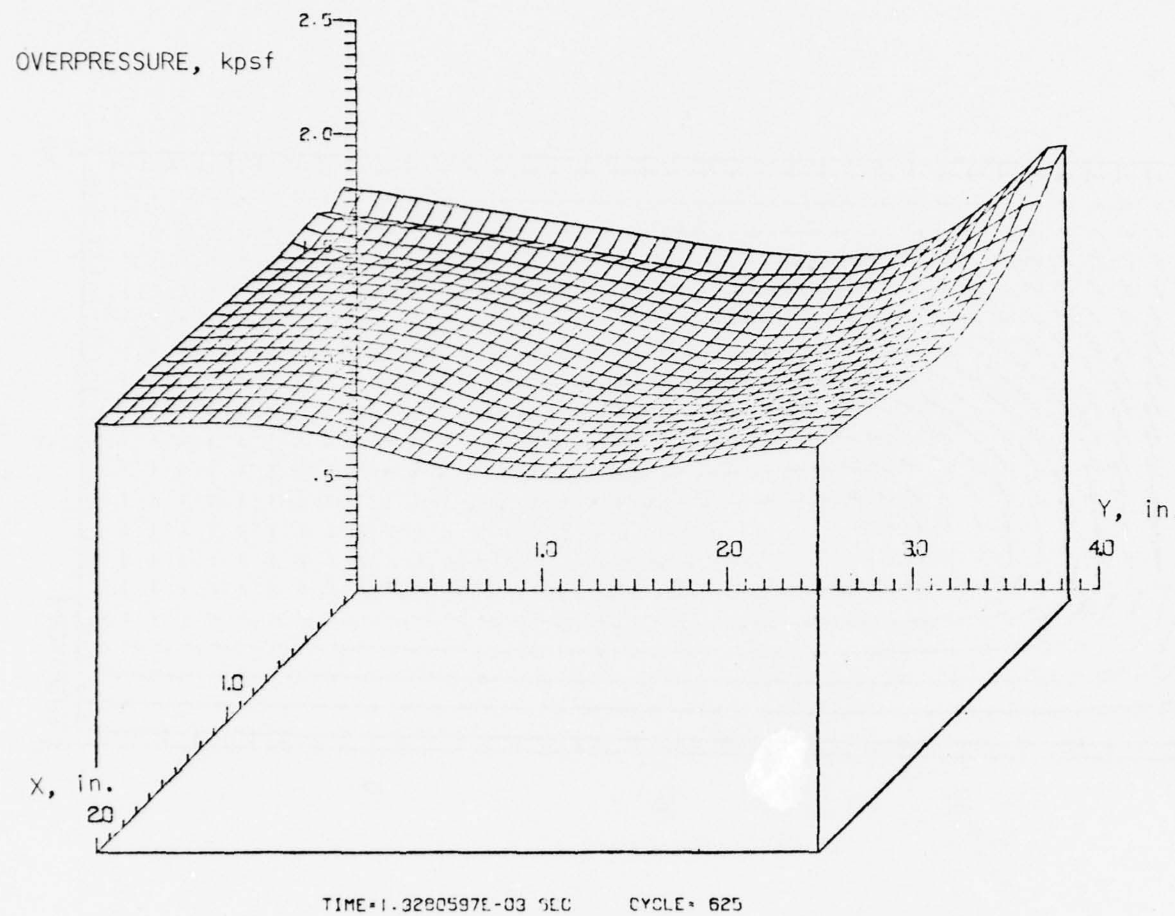
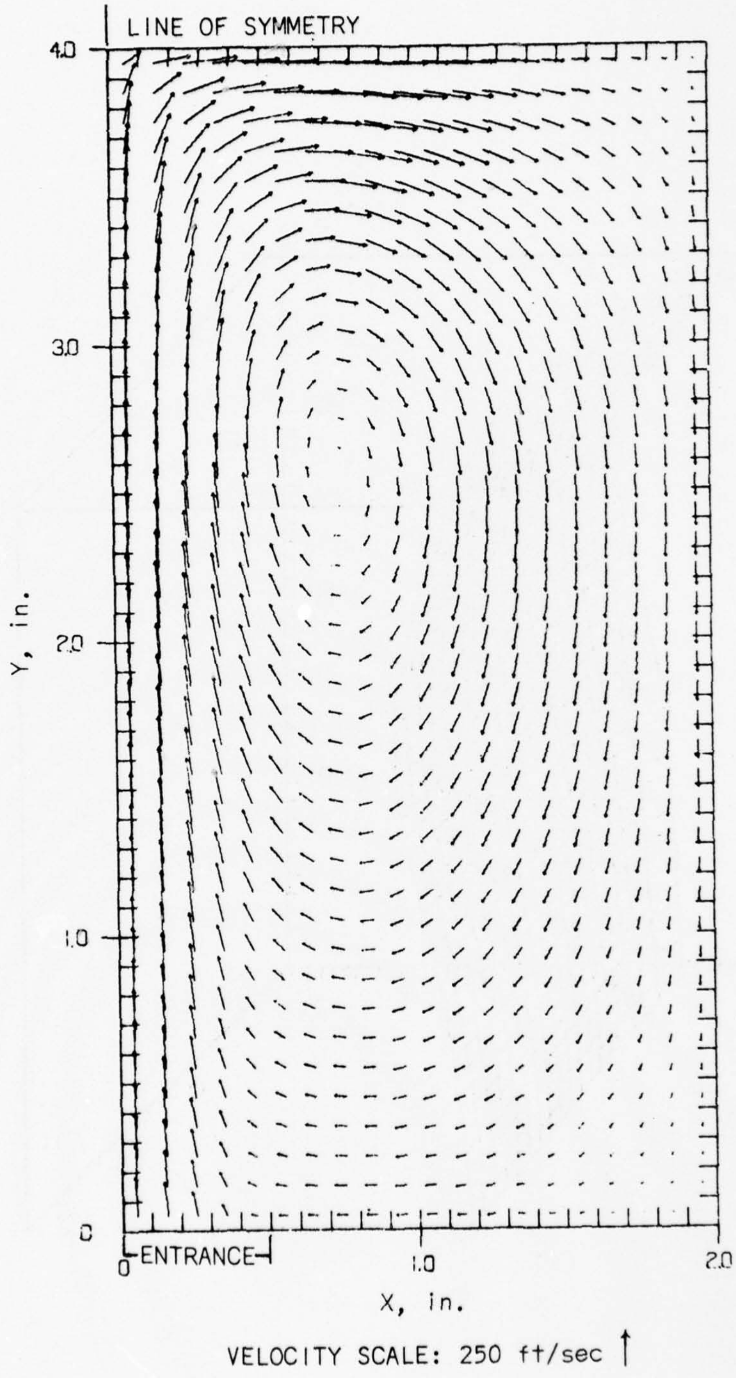


Figure 55. Pressure Field



VELOCITY SCALE: 250 ft/sec

TIME=1.3282597E-03 SEC CYCLE= 525

Figure 56. Velocity Field

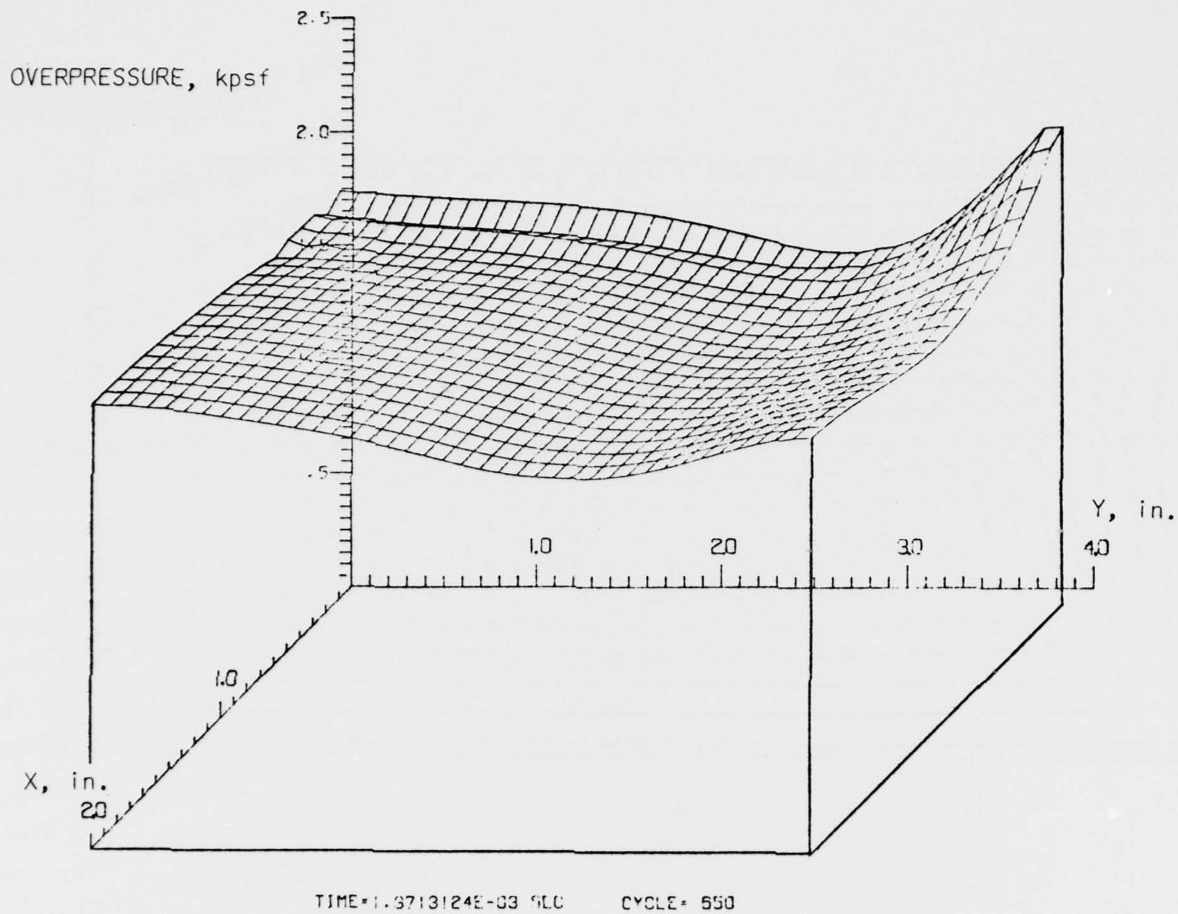


Figure 57. Pressure Field

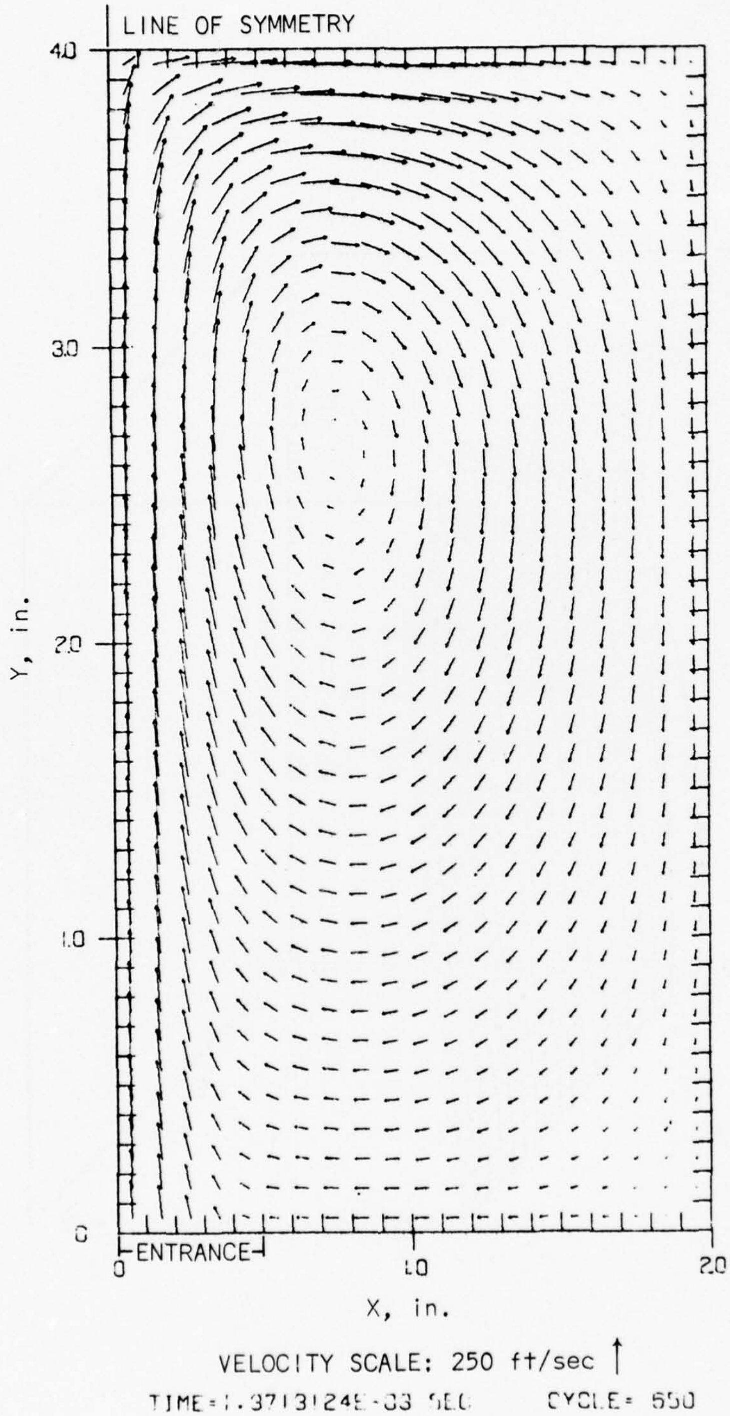


Figure 58. Velocity Field

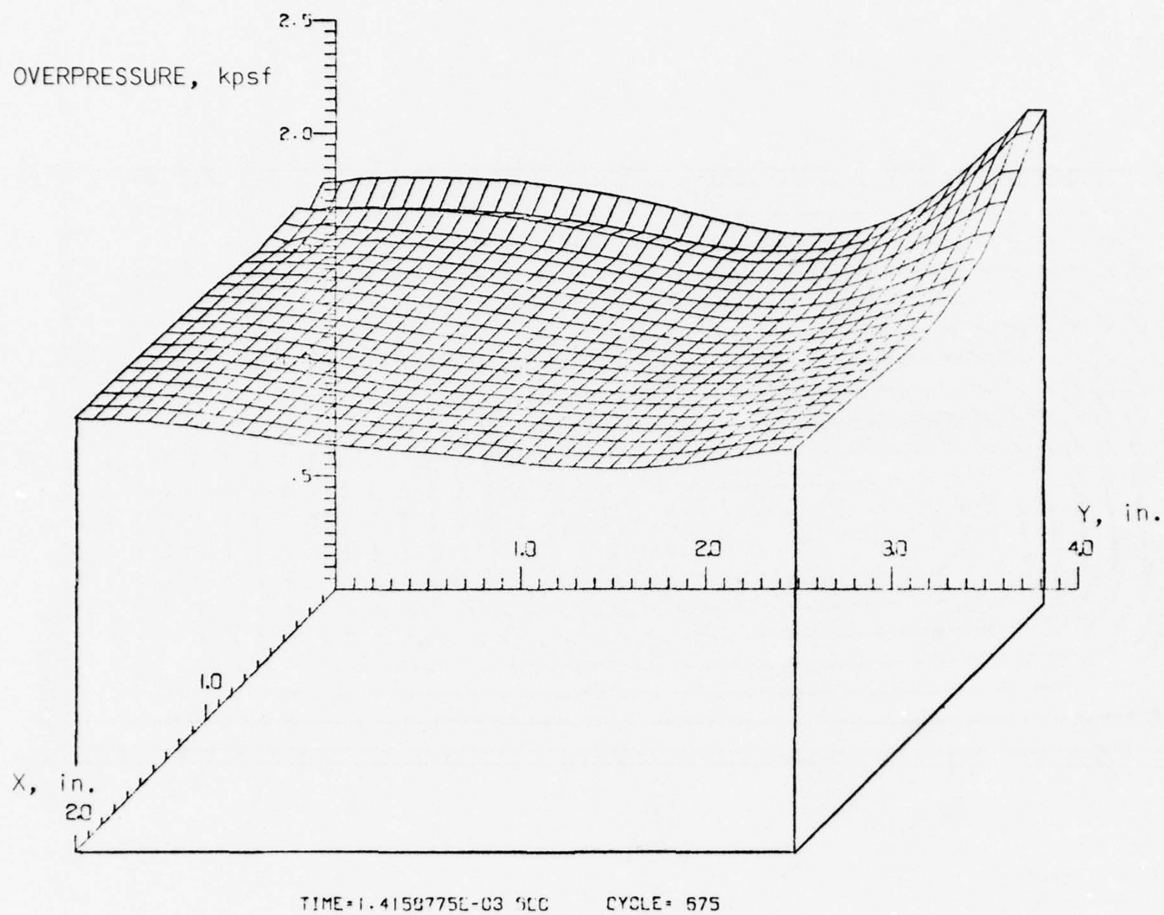


Figure 59. Pressure Field

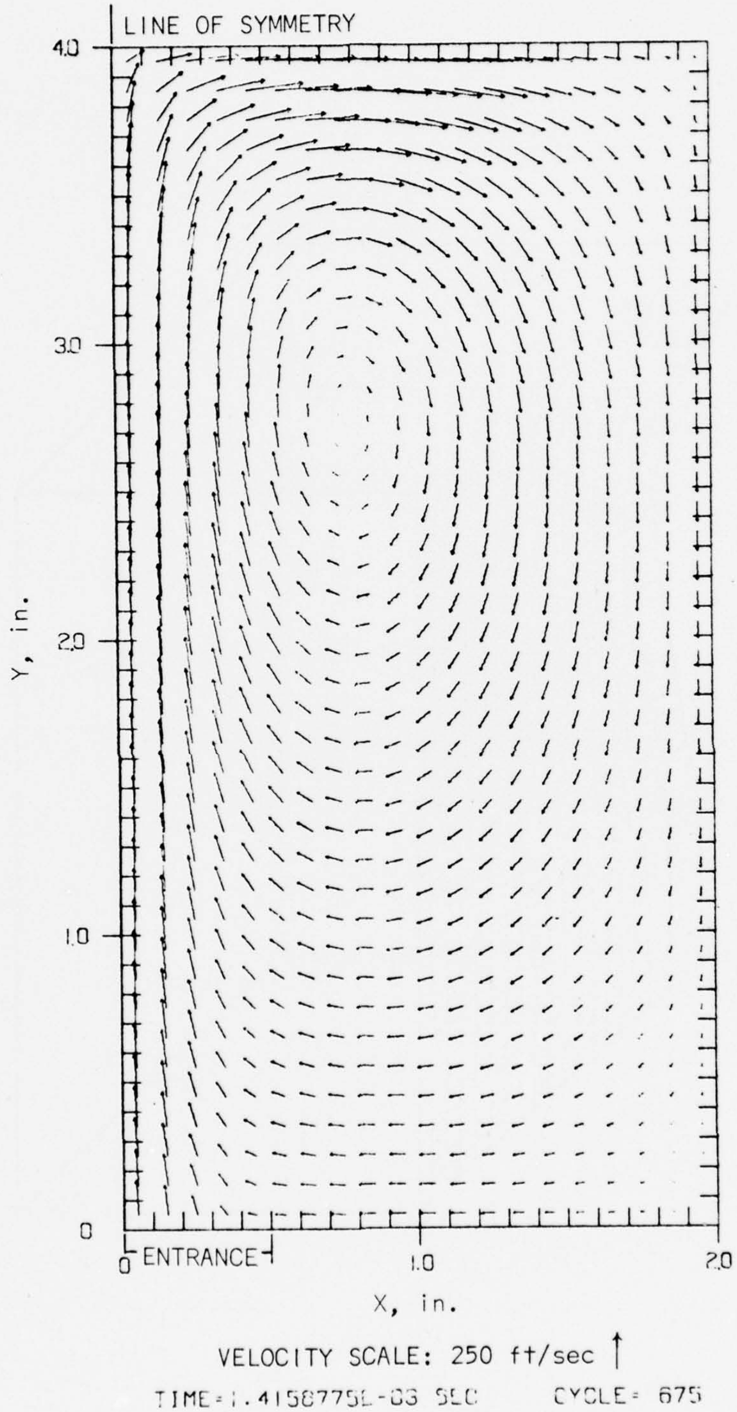


Figure 60. Velocity Field

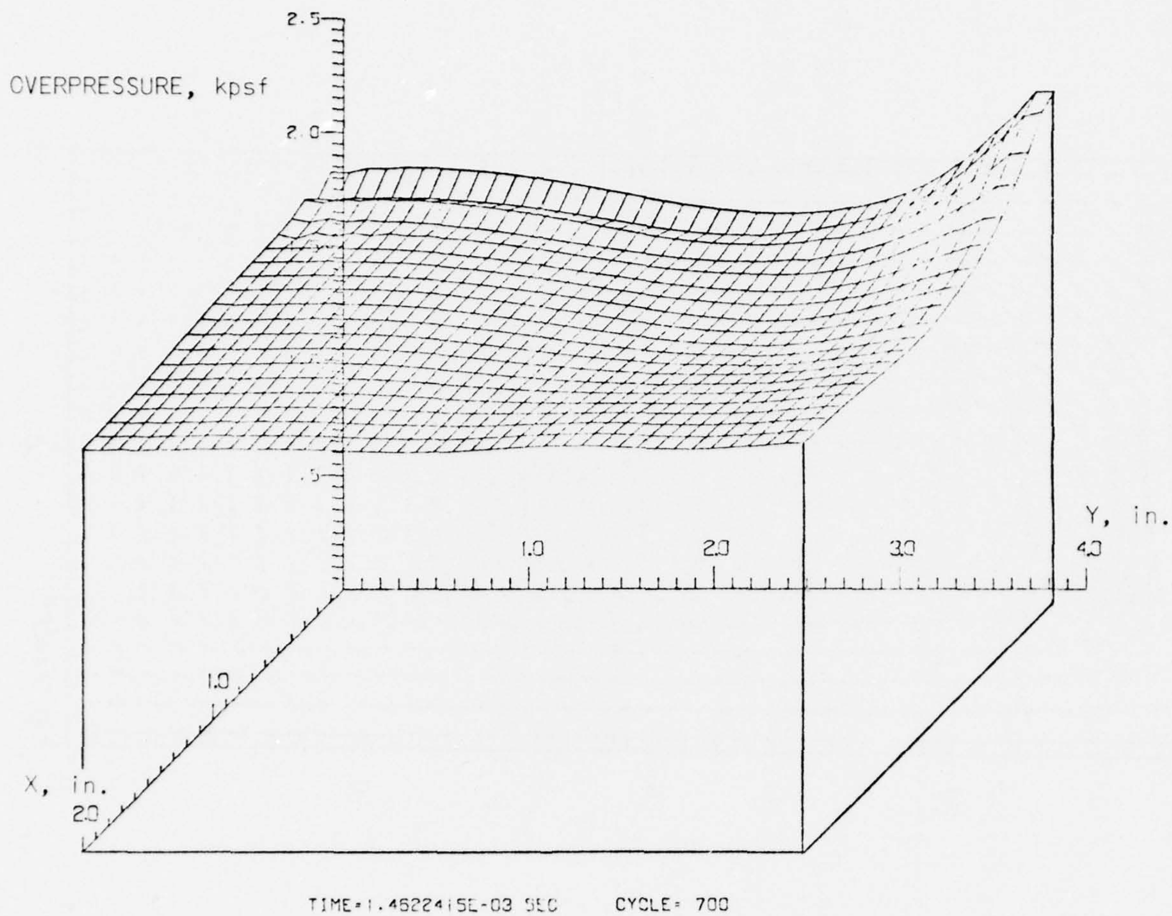
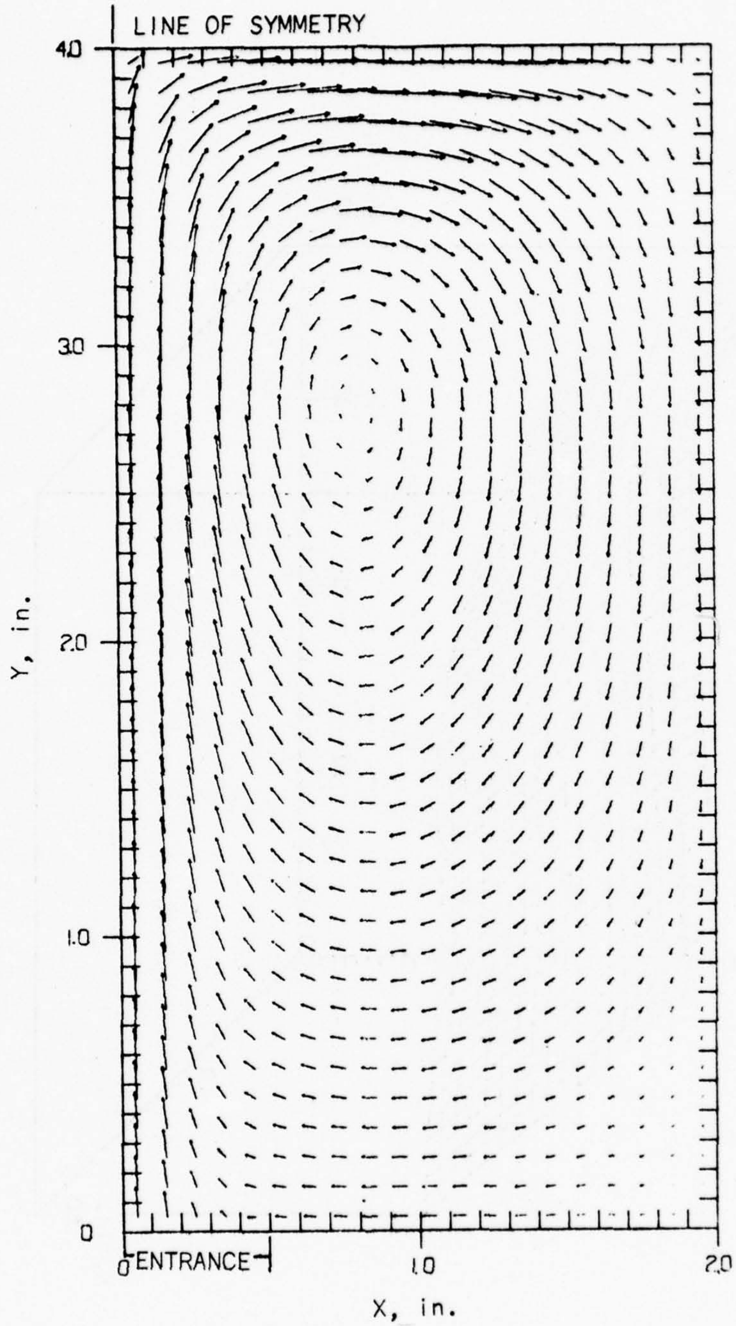


Figure 61. Pressure Field



VELOCITY SCALE: 250 ft/sec ↑

TIME=1.46224150-03 SEC CYCLE= 700

Figure 62. Velocity Field

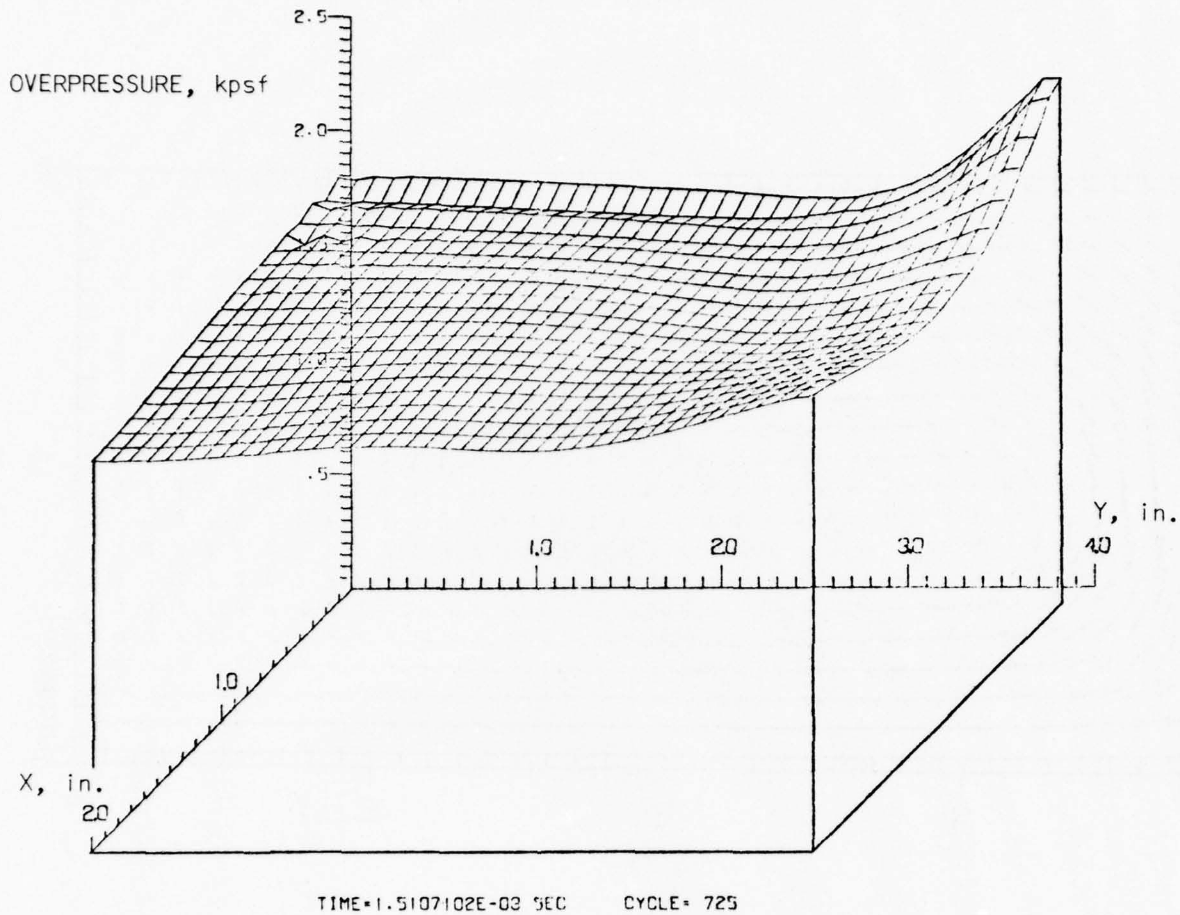


Figure 63. Pressure Field

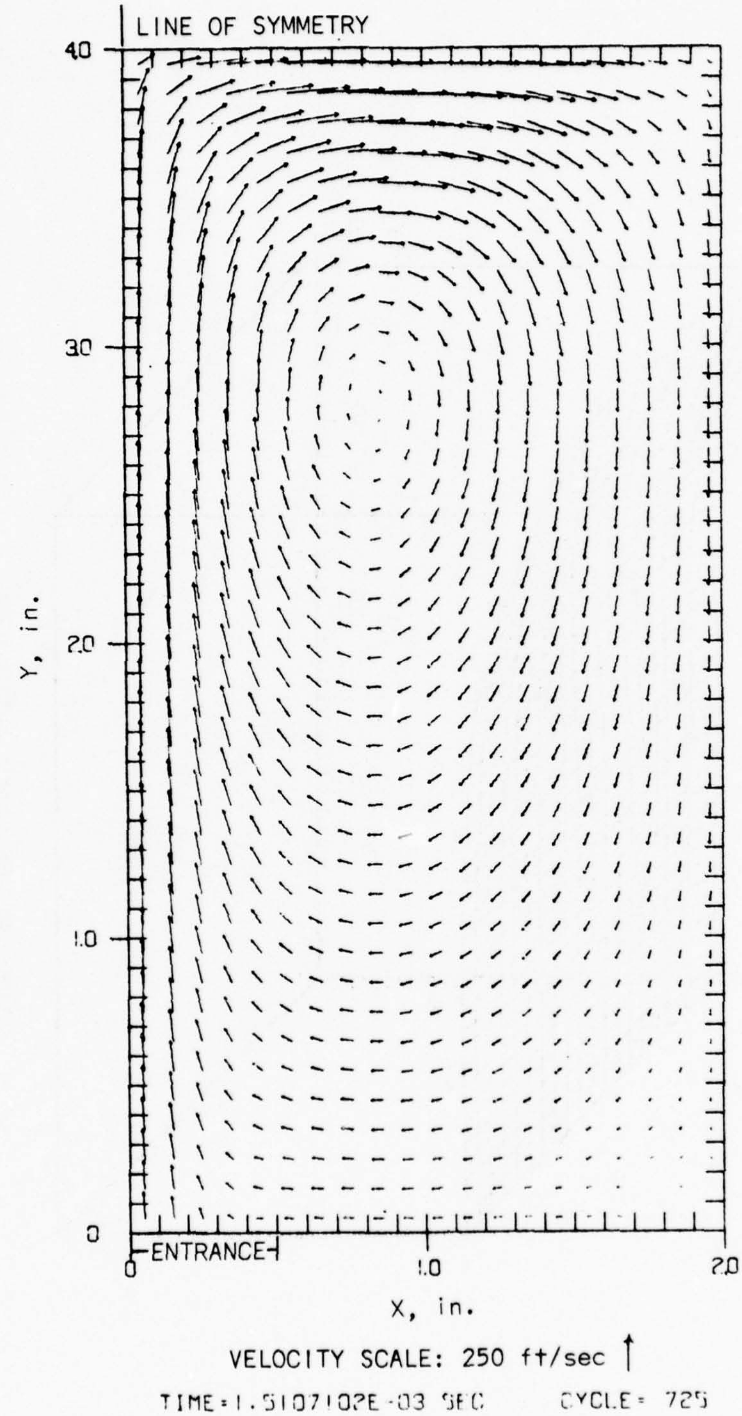


Figure 64. Velocity Field

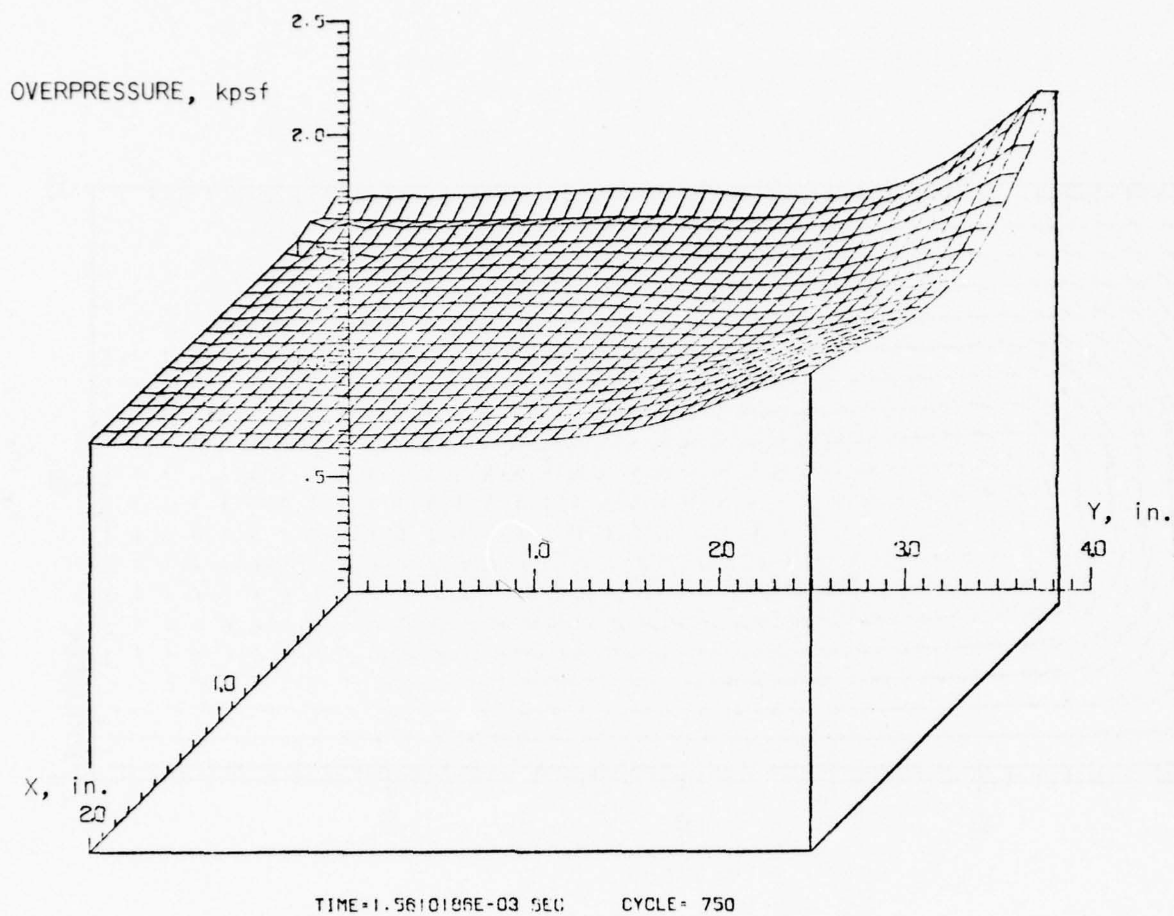


Figure 65. Pressure Field

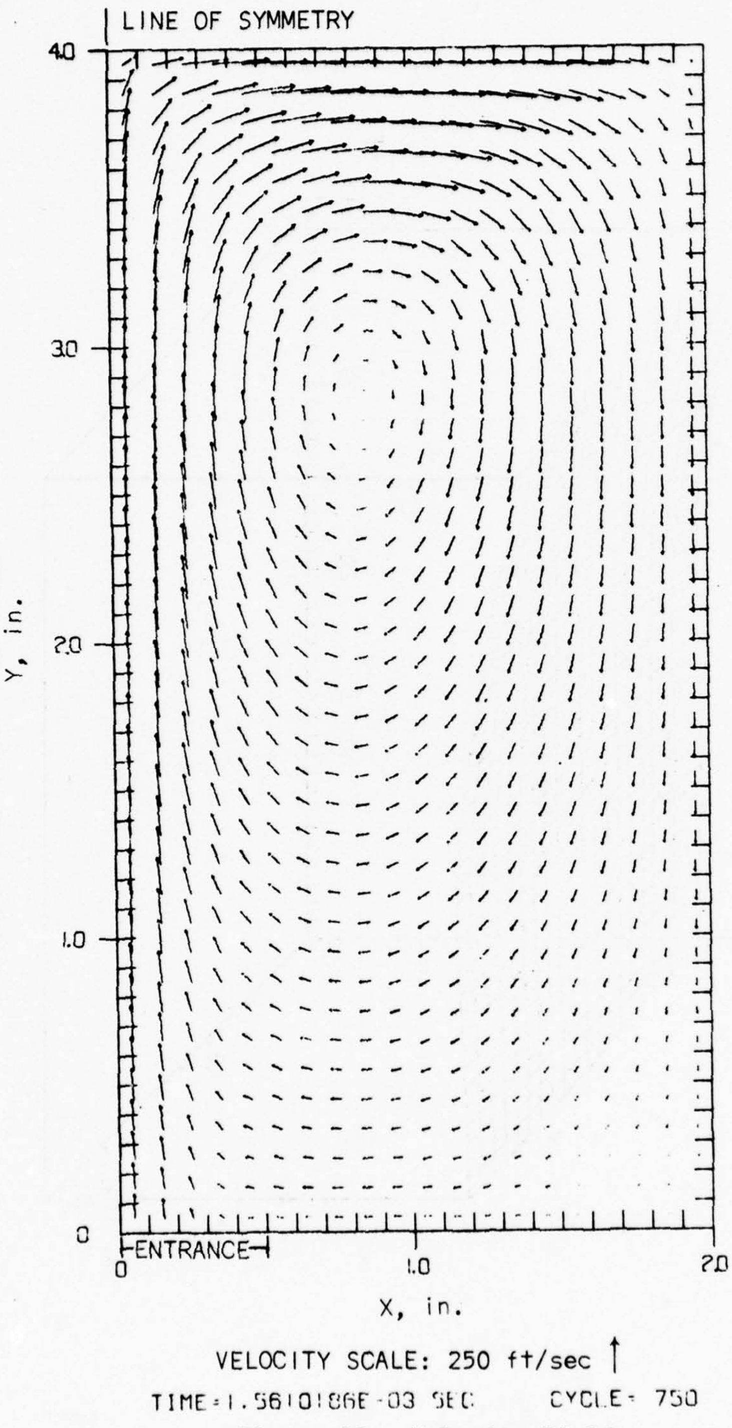


Figure 66. Velocity Field

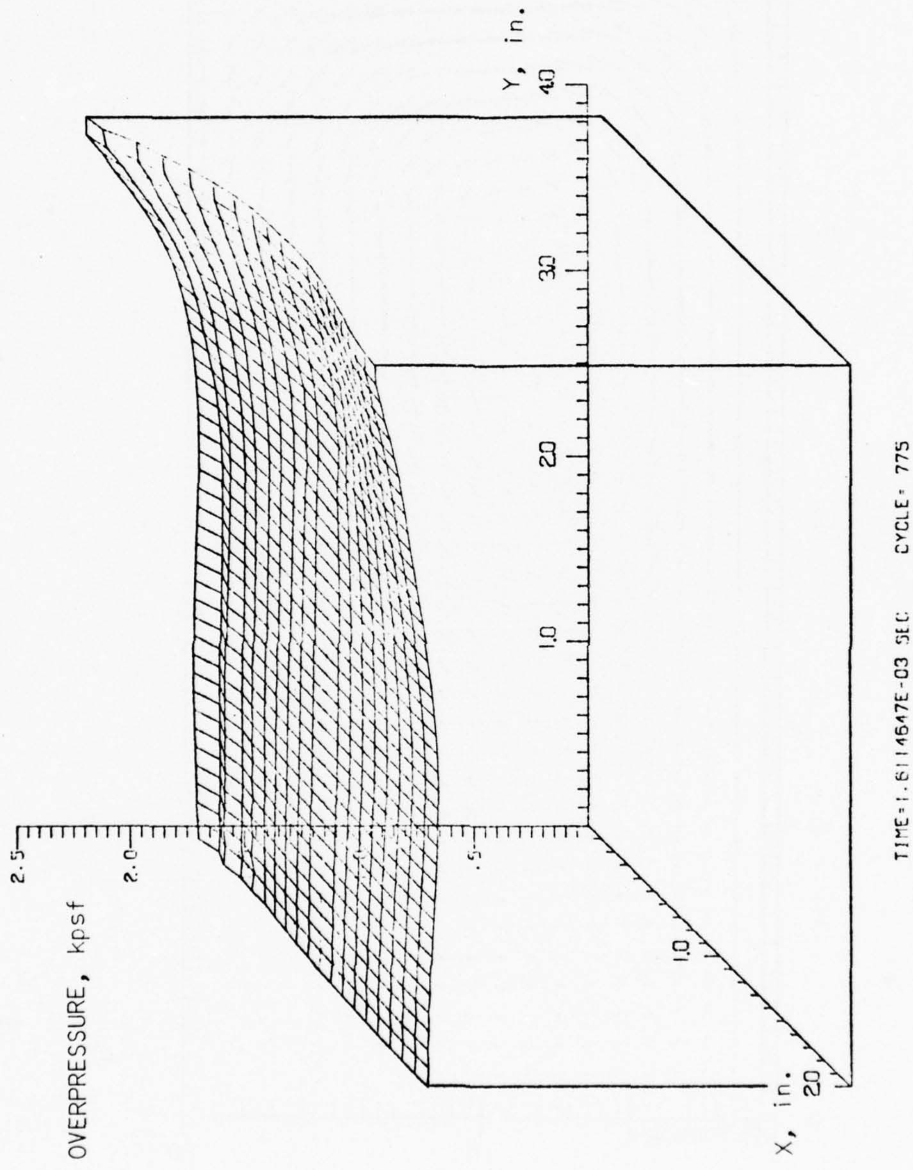


Figure 67. Pressure Field

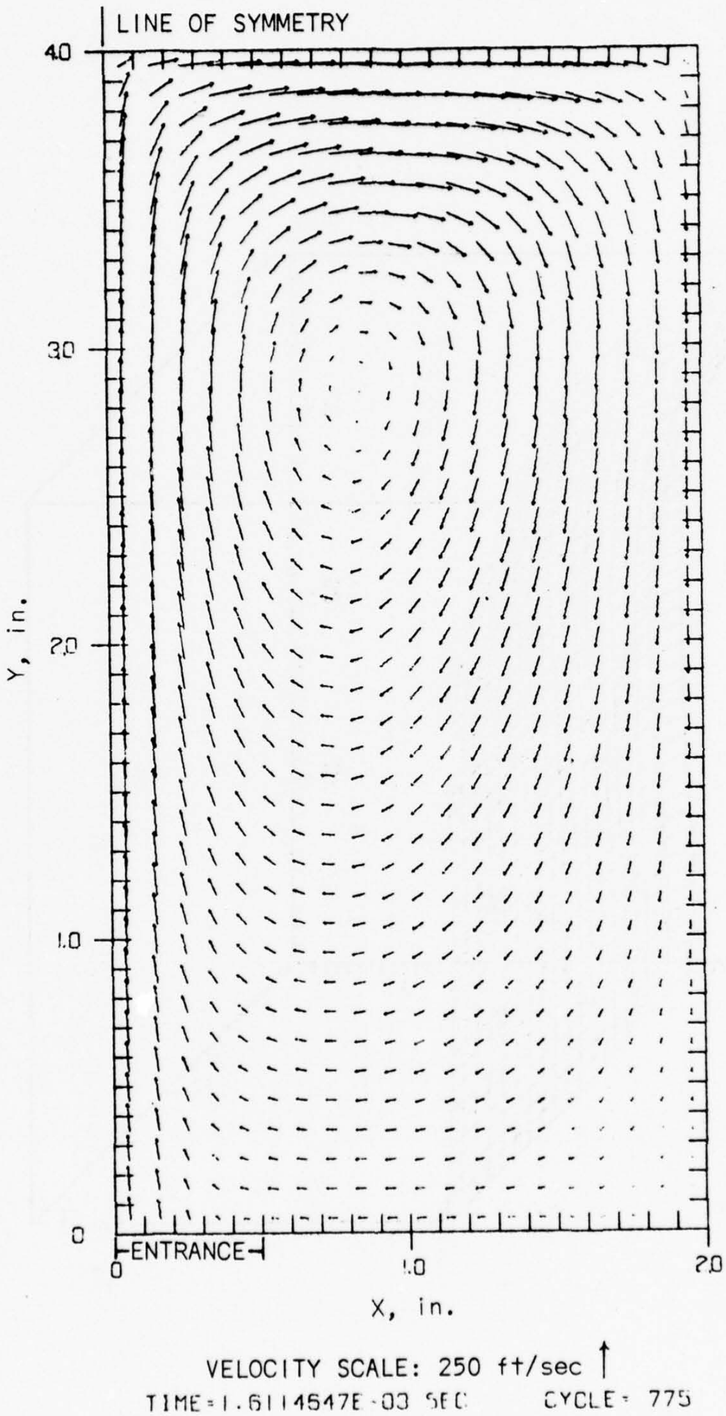


Figure 68. Velocity Field

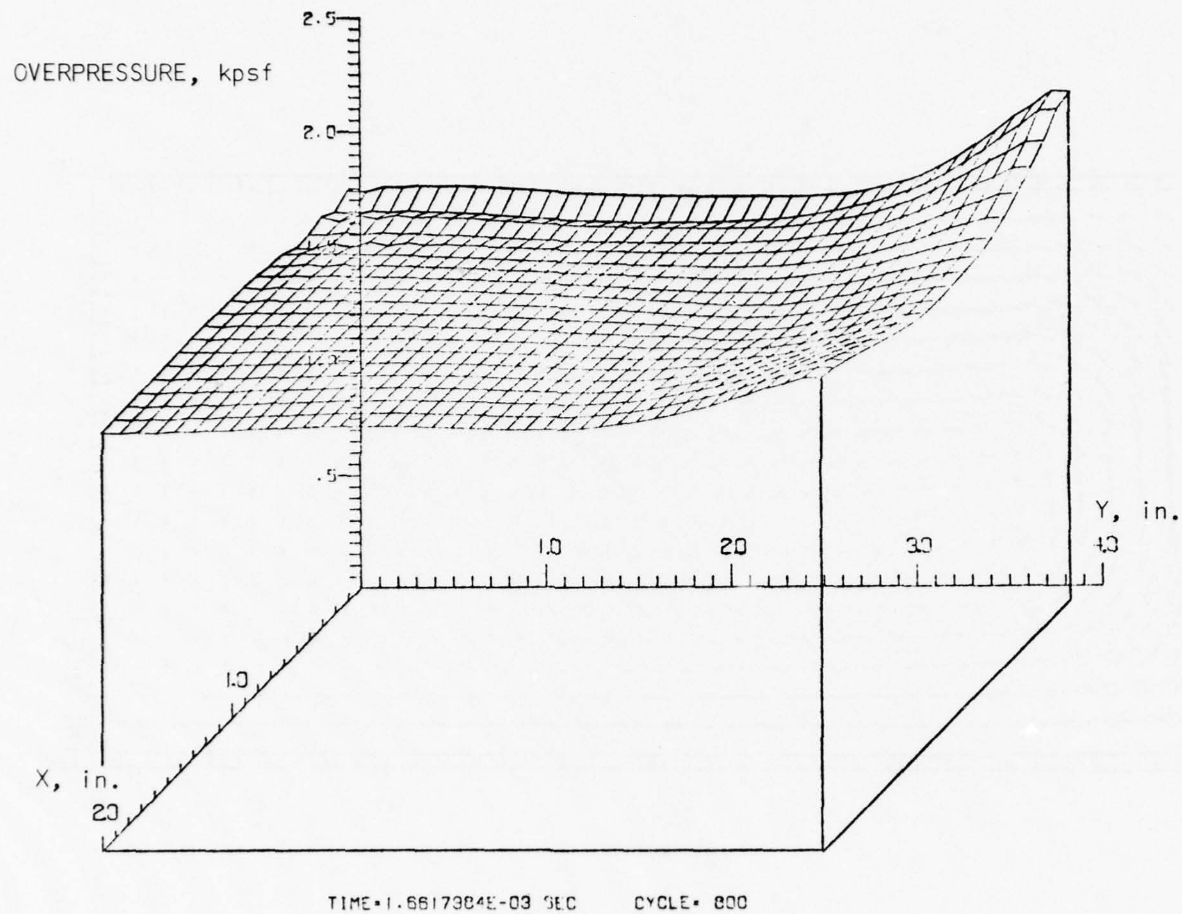


Figure 69. Pressure Field

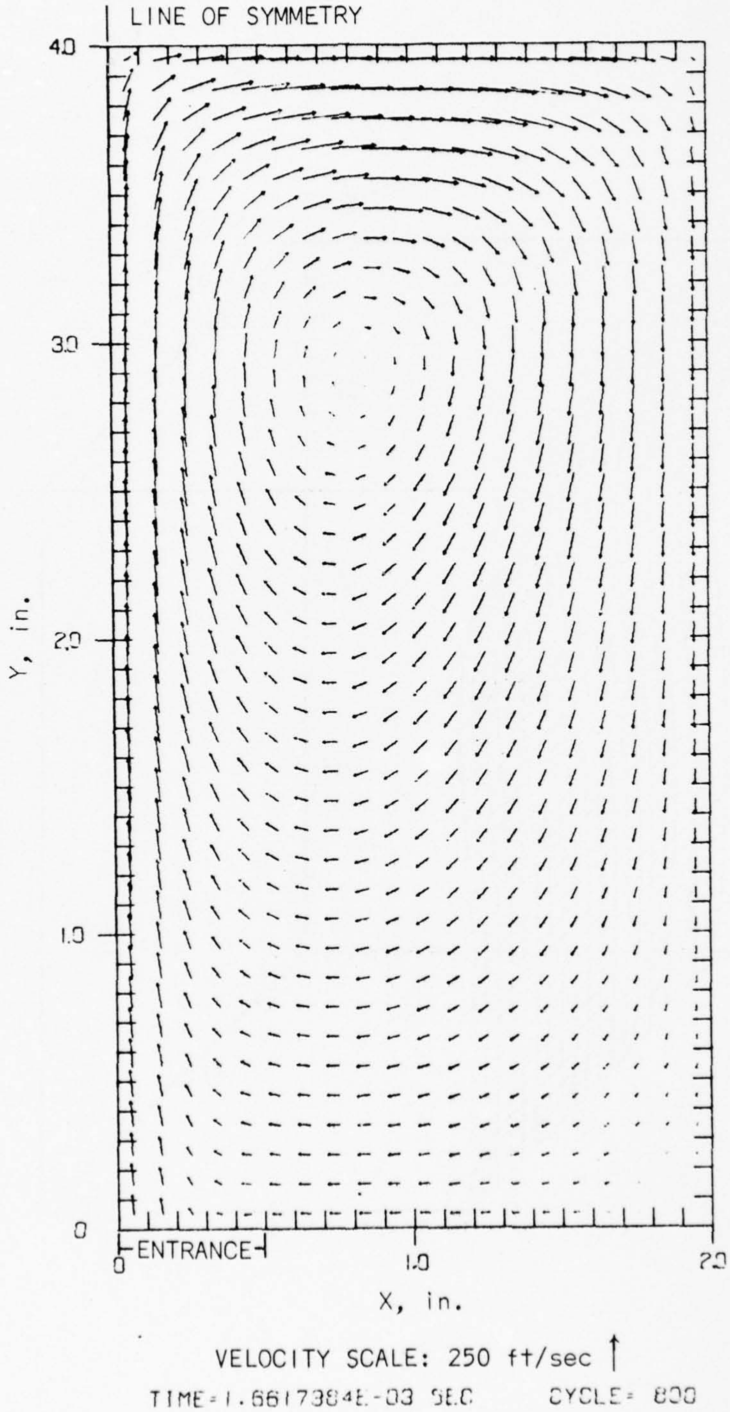


Figure 70. Velocity Field

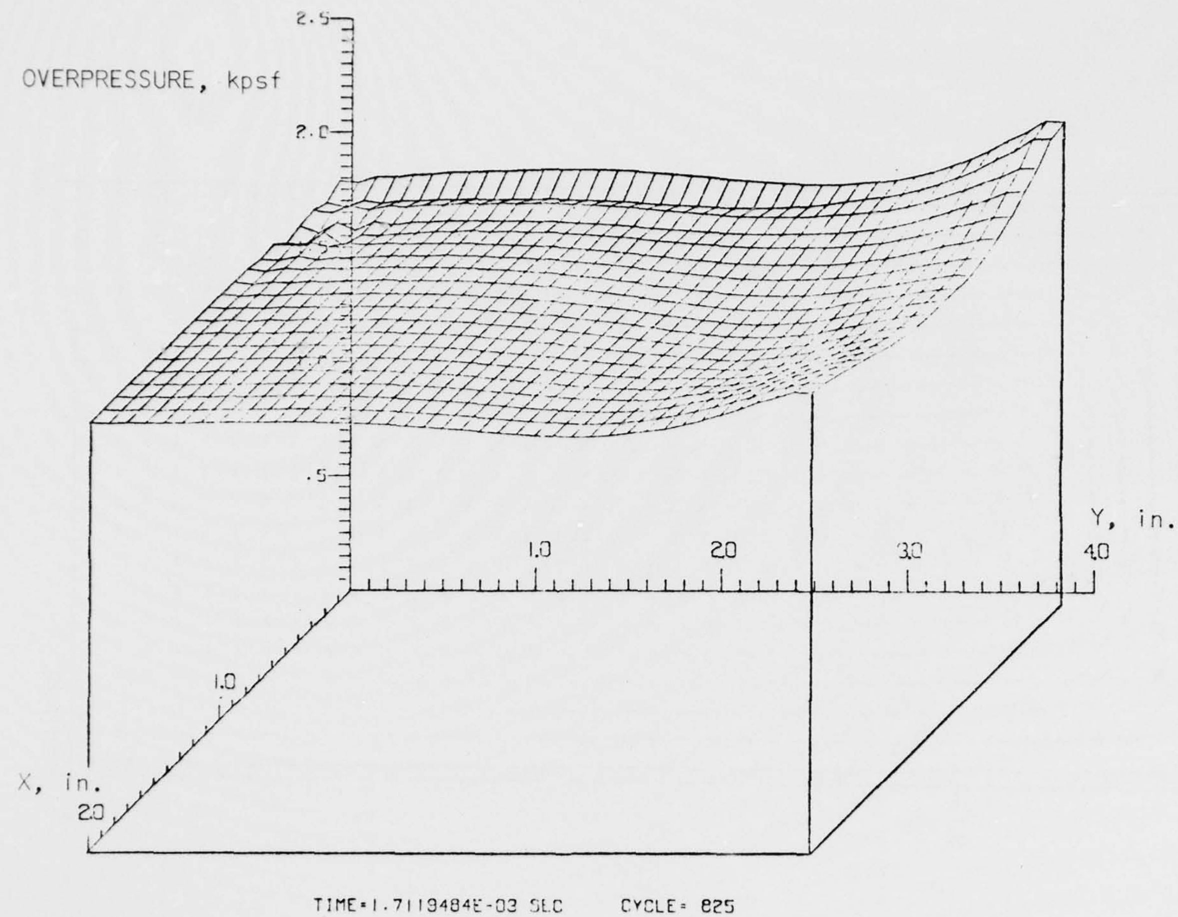


Figure 71. Pressure Field

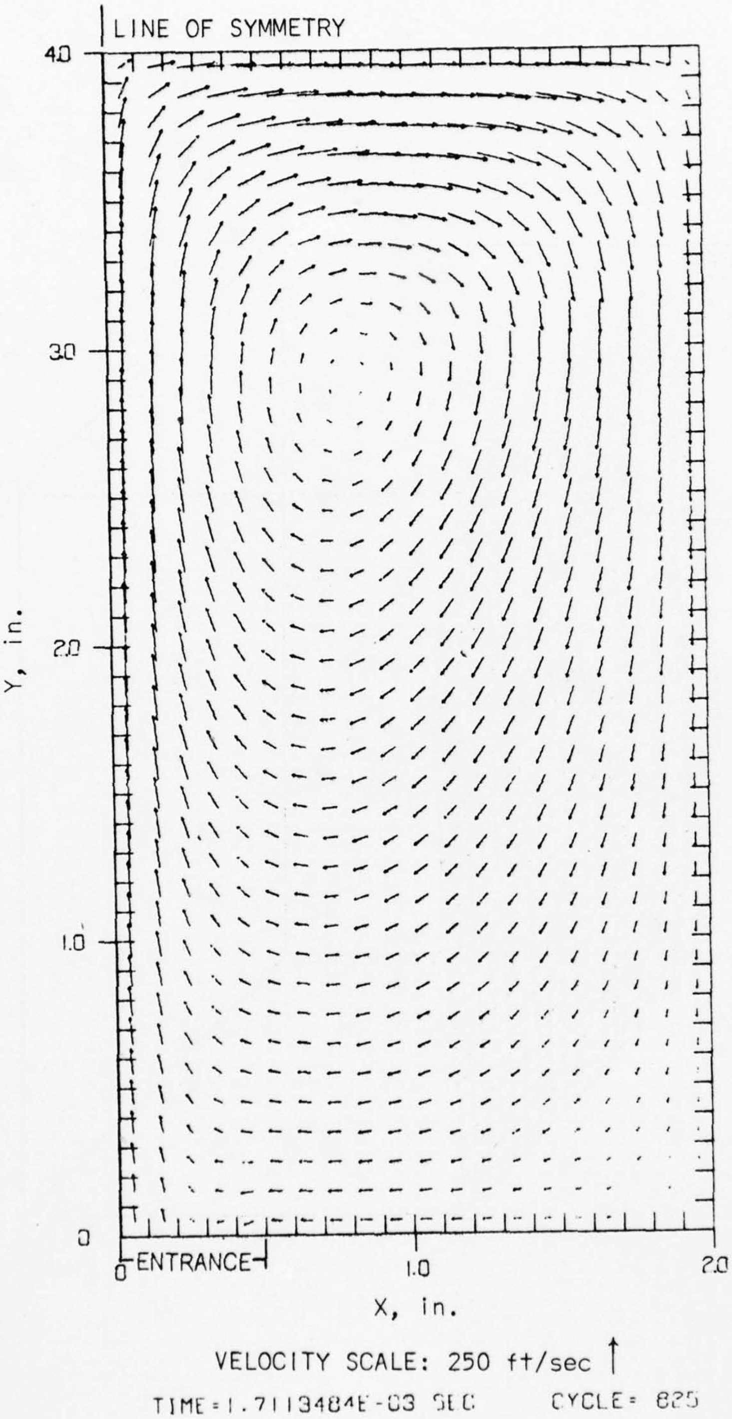


Figure 72. Velocity Field

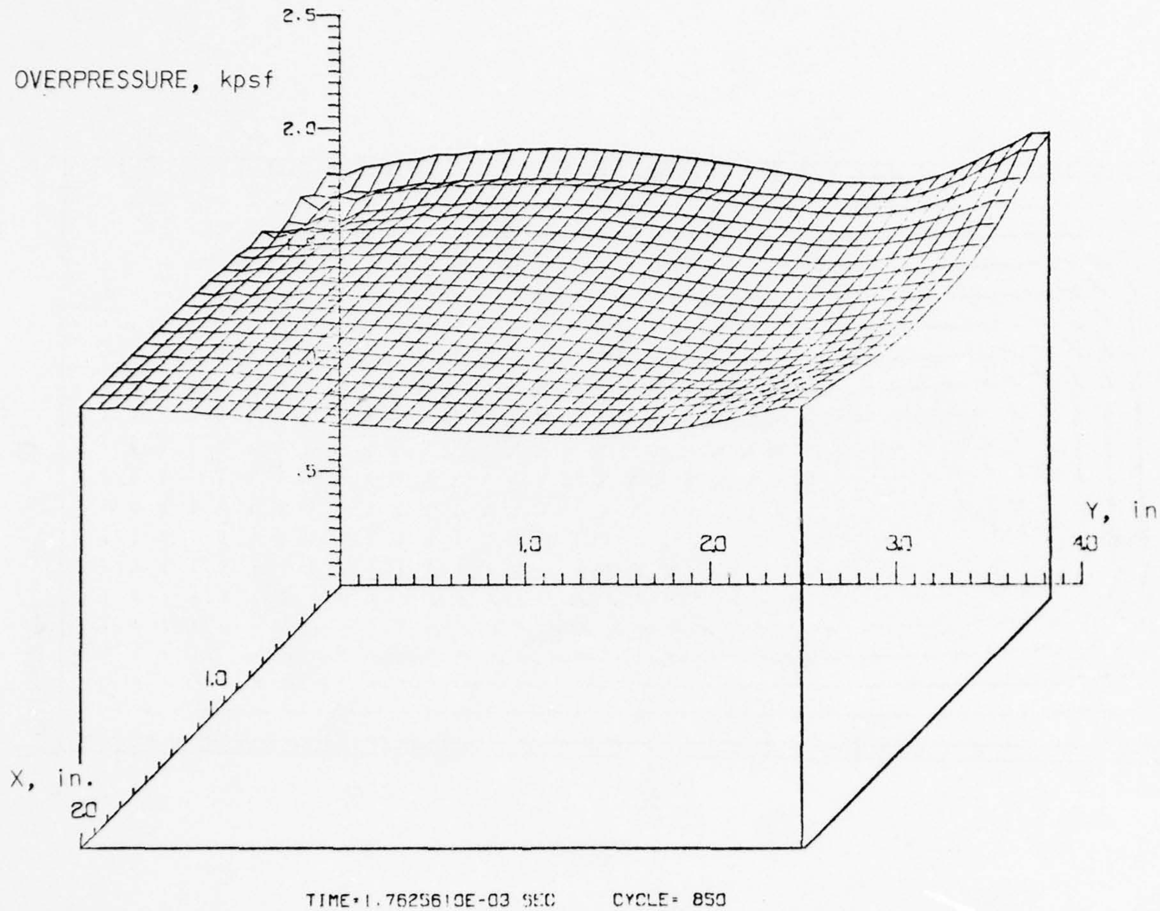


Figure 73. Pressure Field

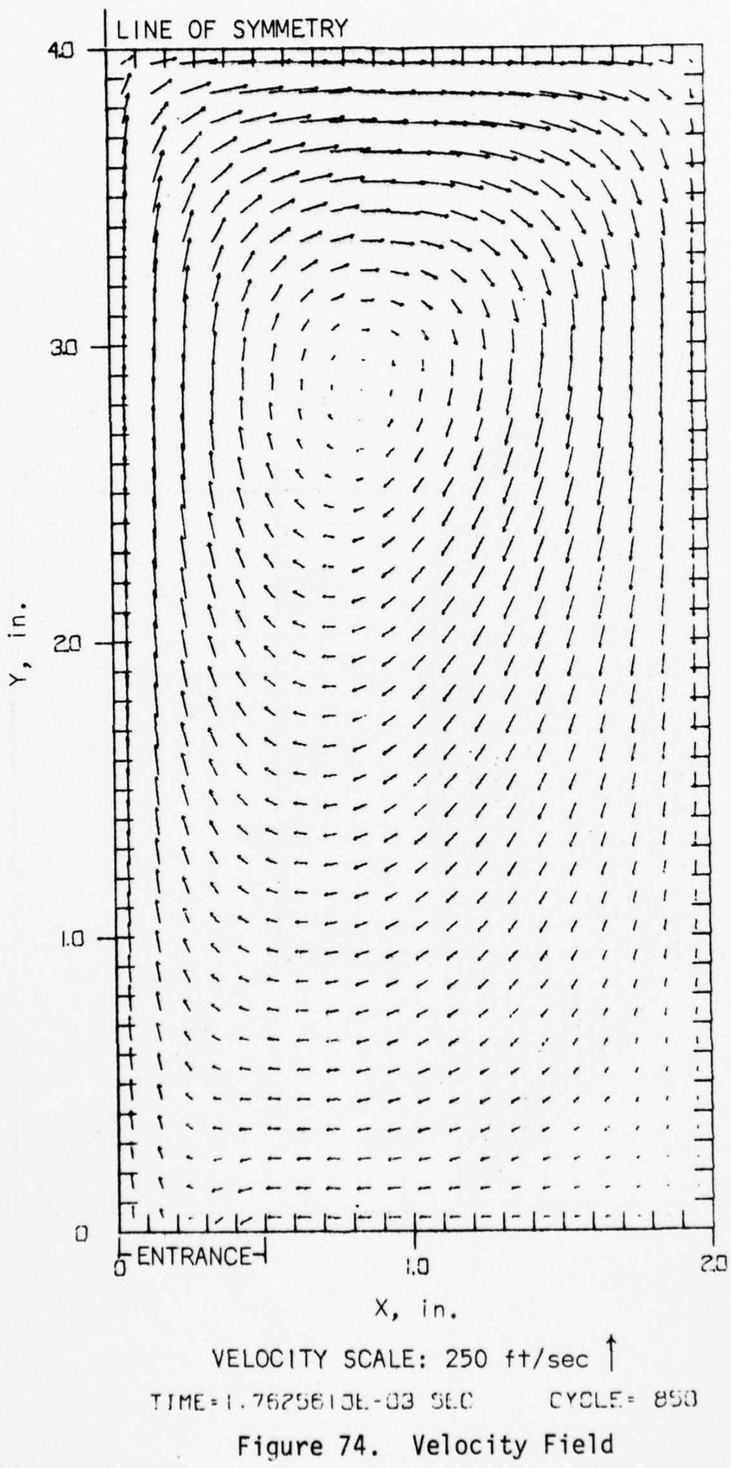
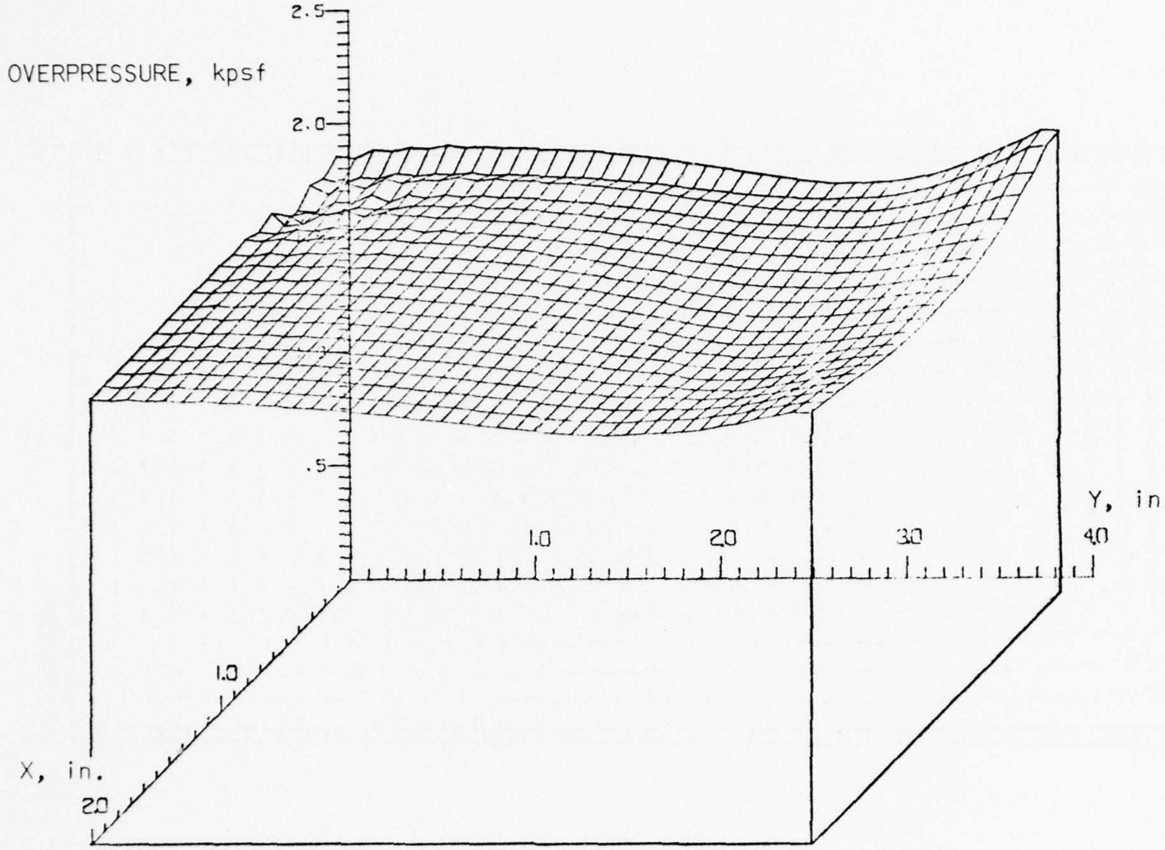


Figure 74. Velocity Field



TIME=1.8146868E-03 SEC CYCLE= 875

Figure 75. Pressure Field

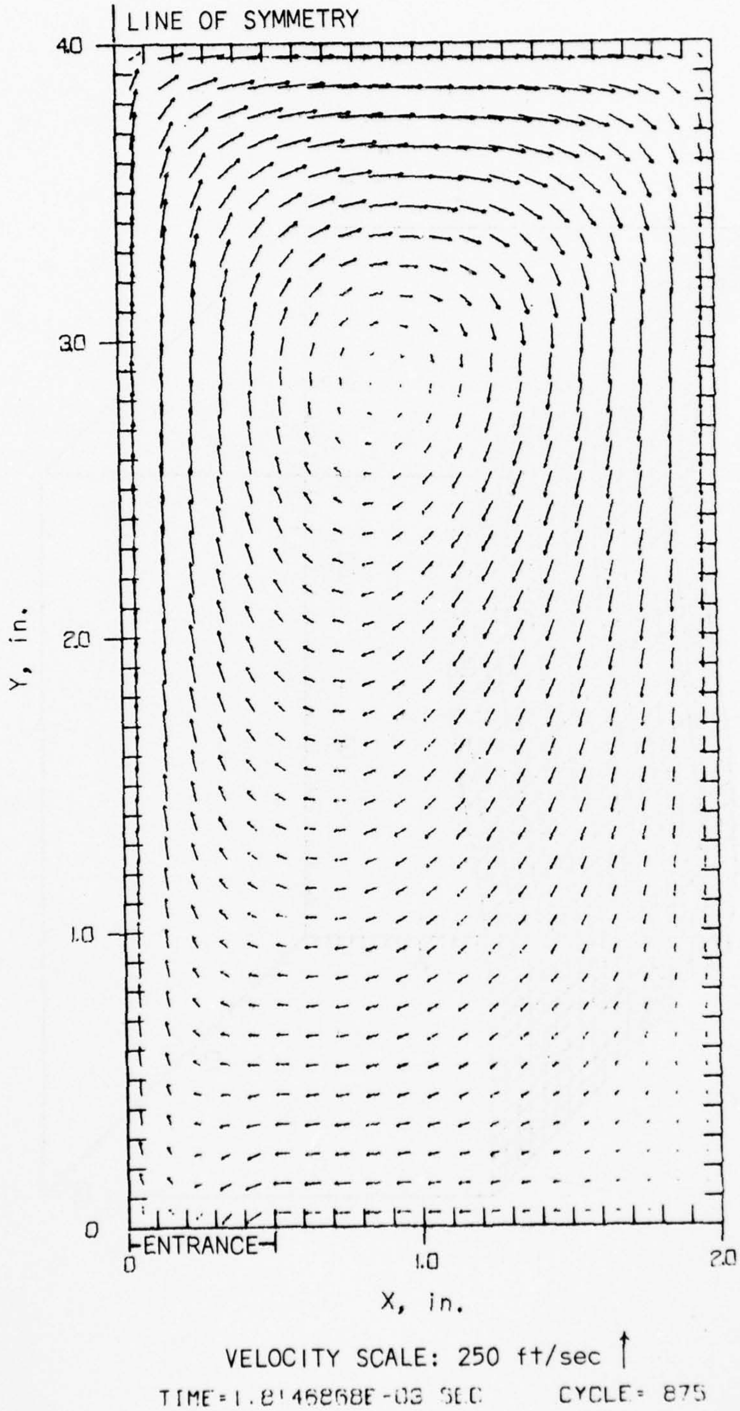


Figure 76. Velocity Field

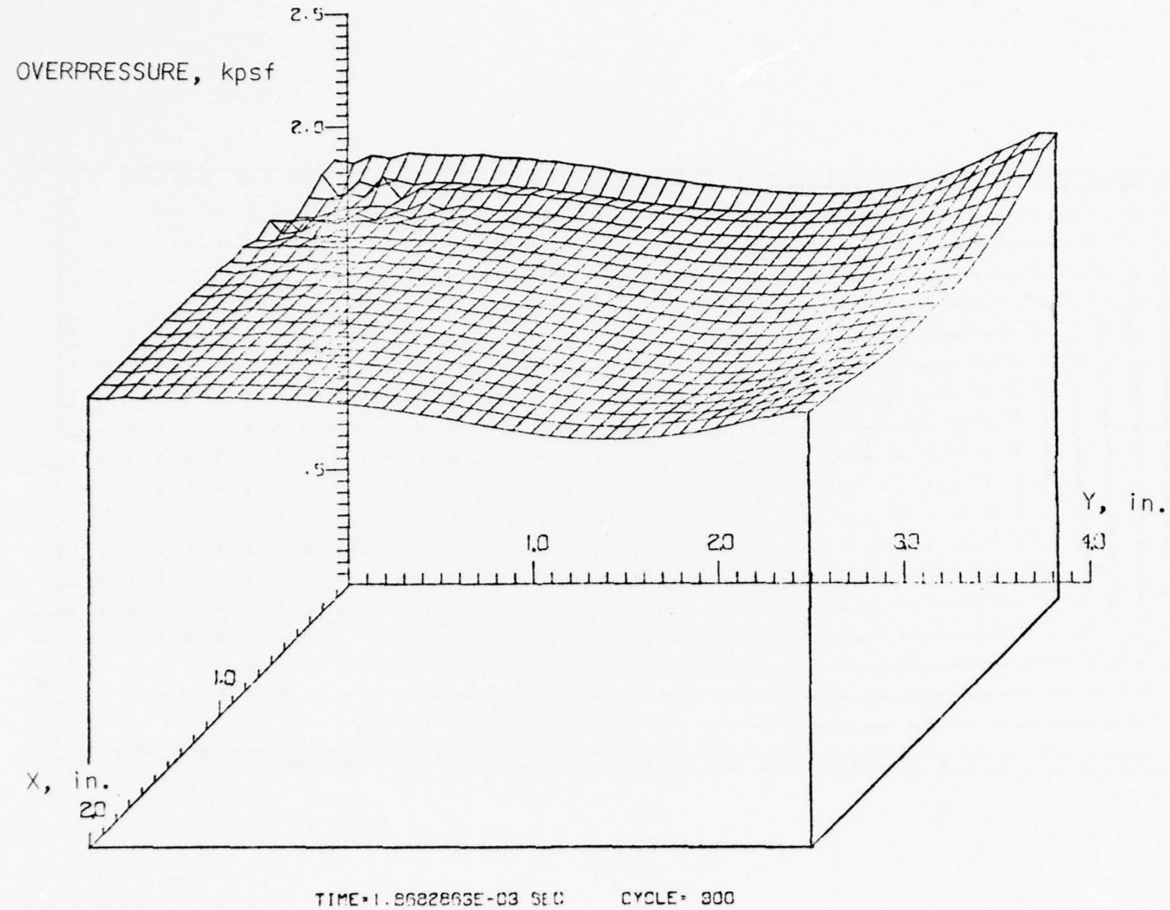


Figure 77. Pressure Field

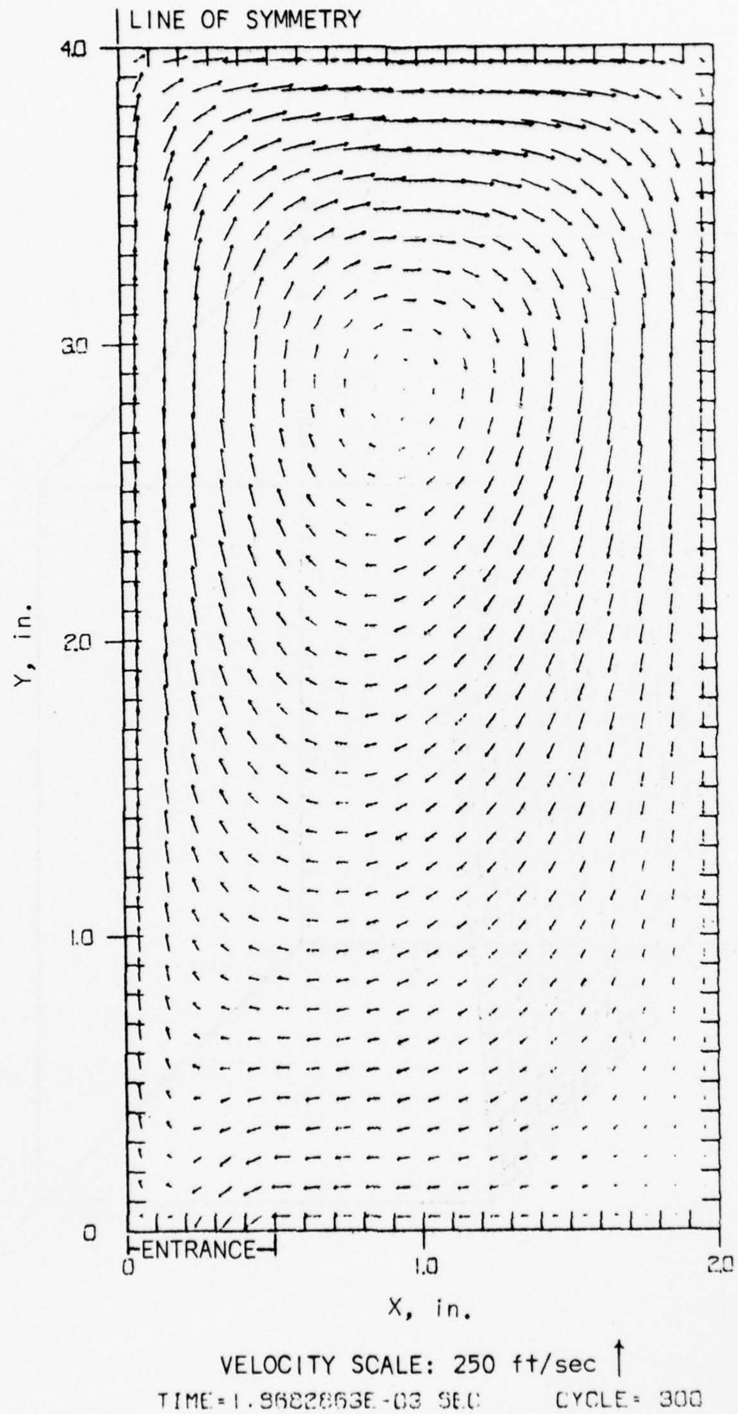


Figure 78. Velocity Field

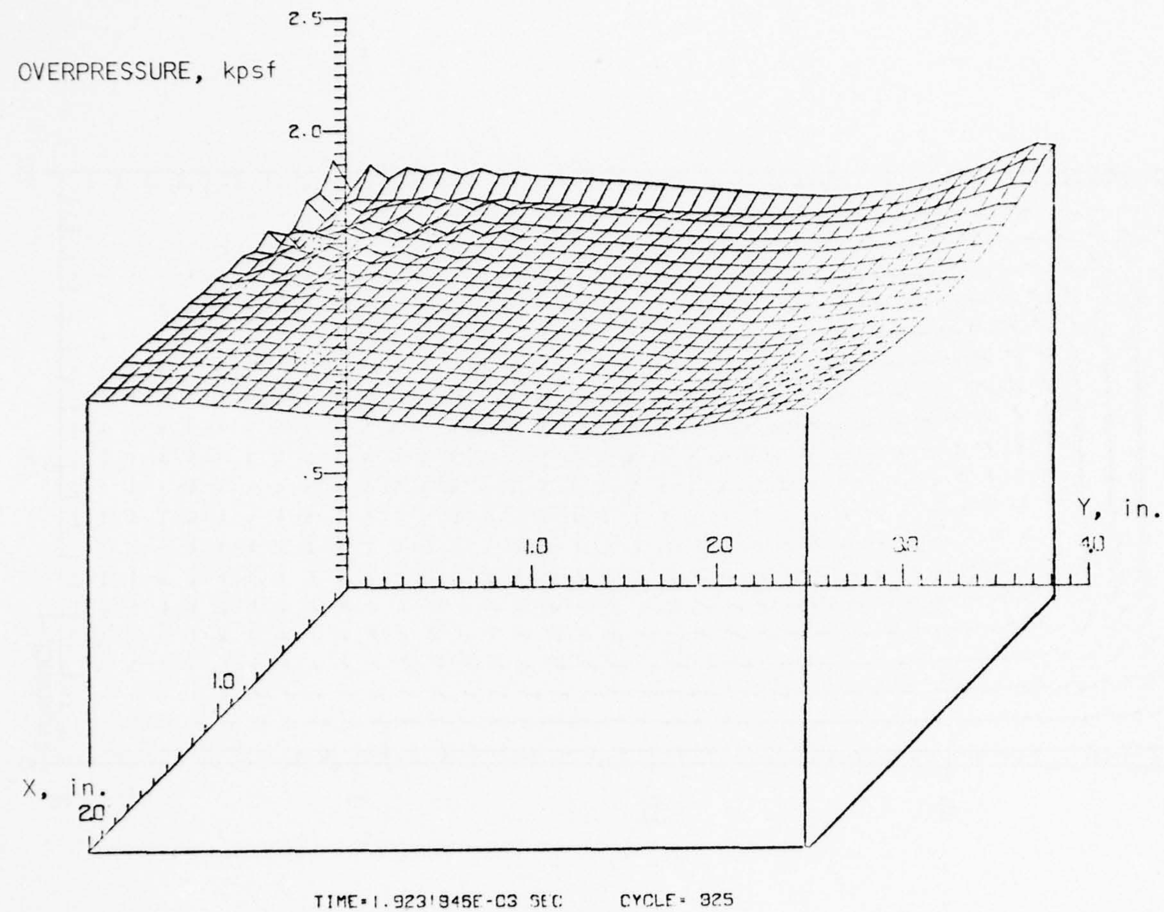


Figure 79. Pressure Field

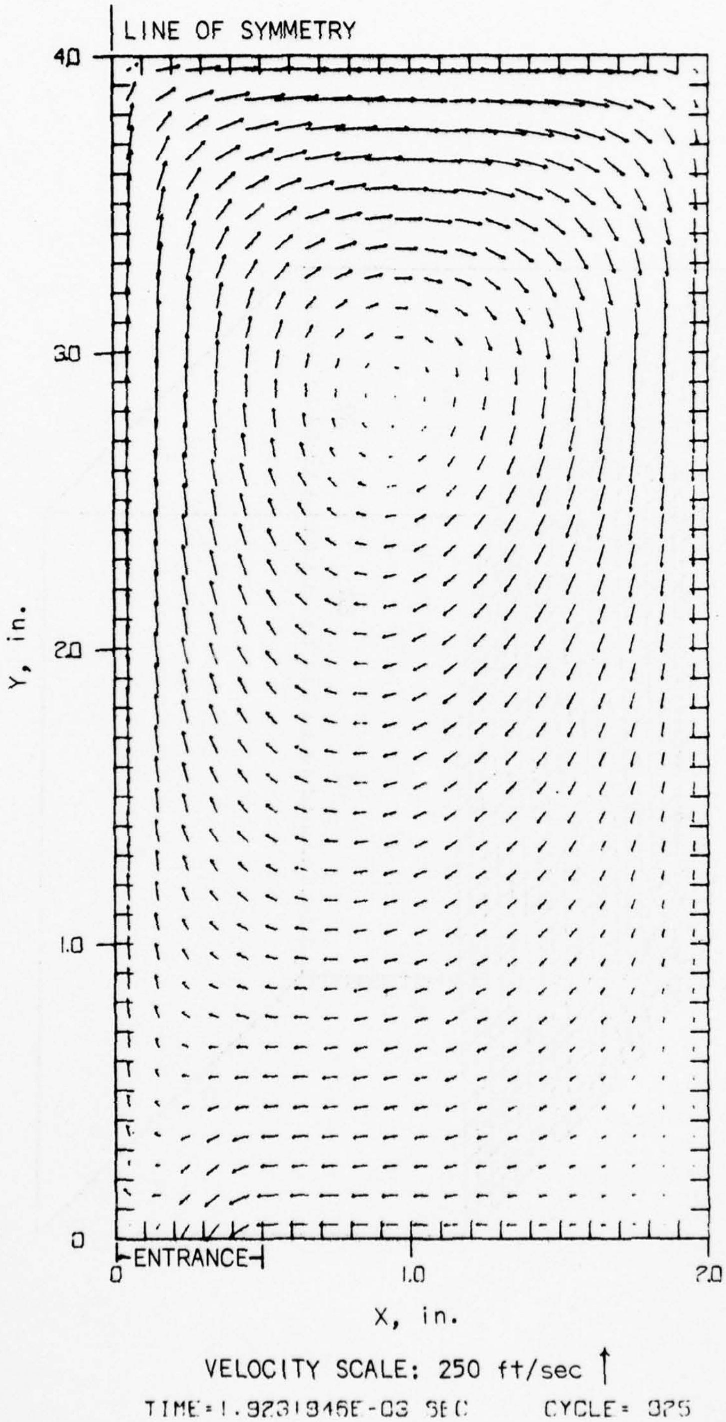


Figure 80. Velocity Field

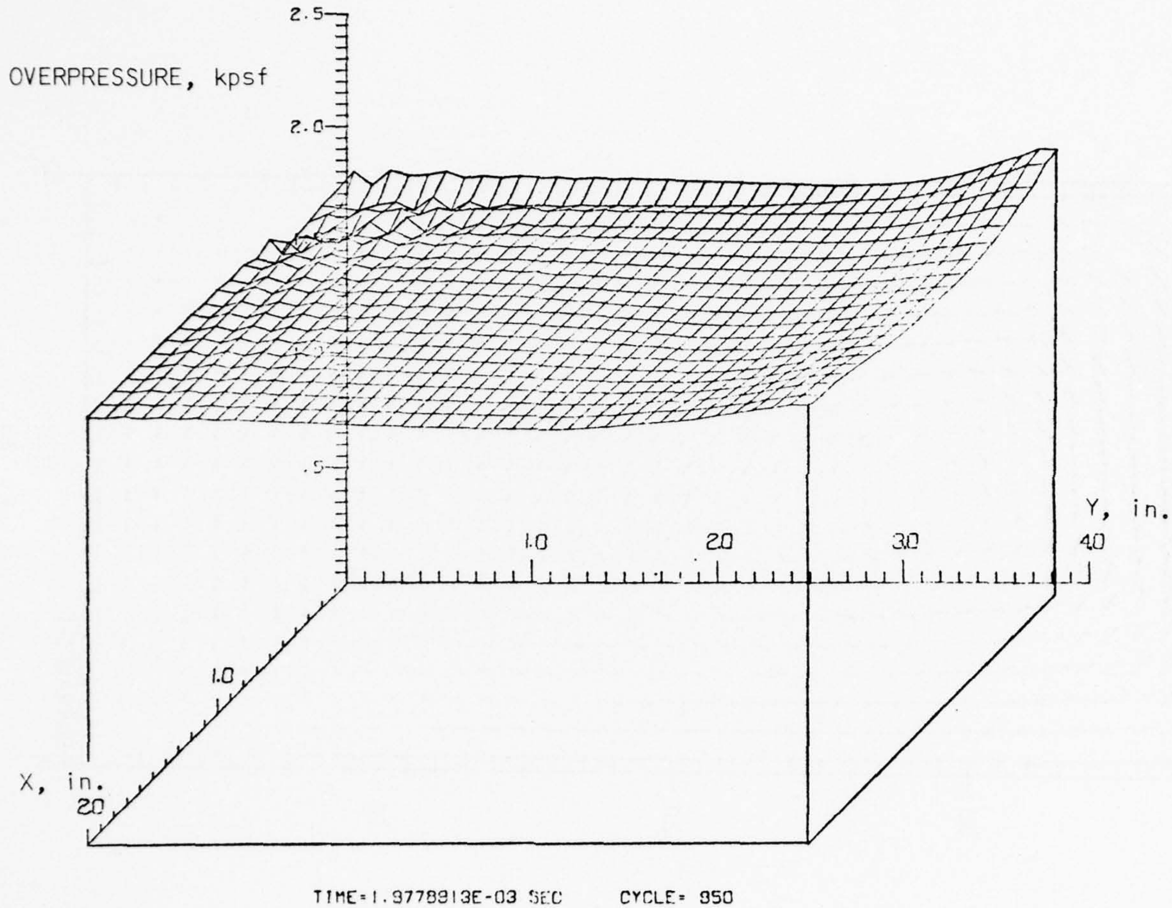
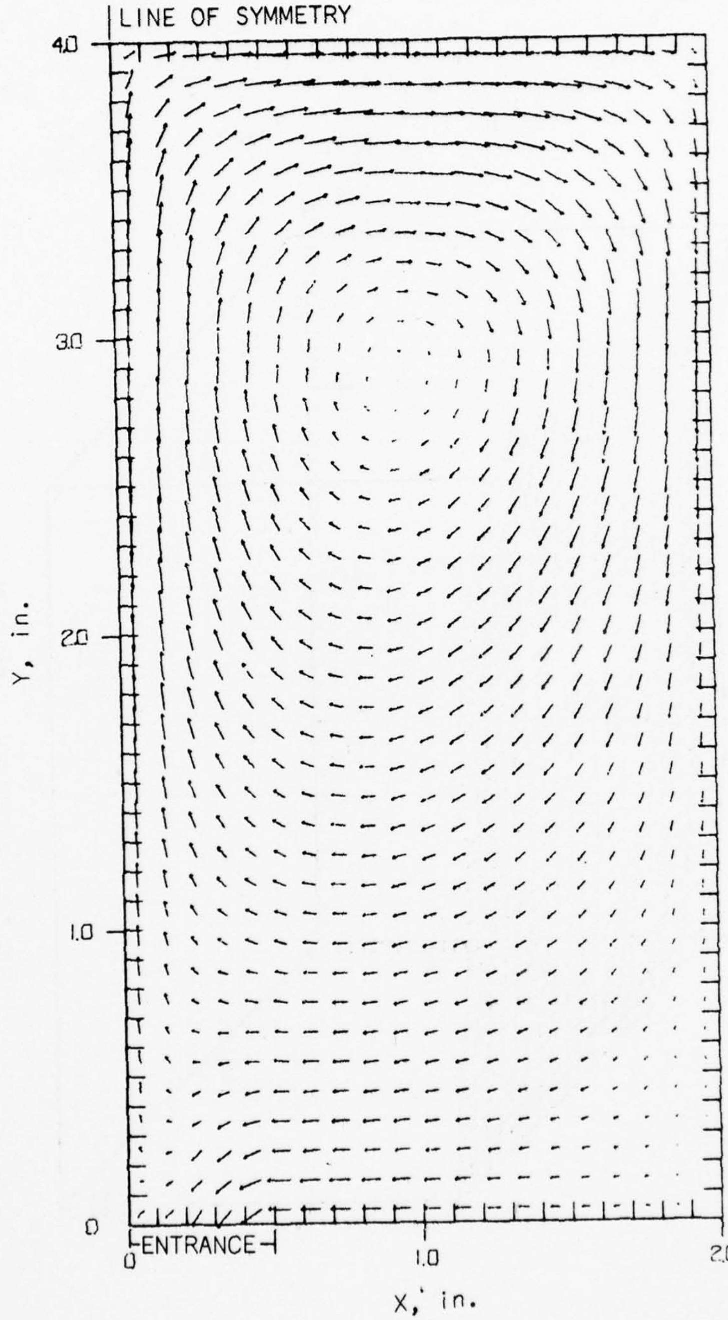


Figure 81. Pressure Field



VELOCITY SCALE: 250 ft/sec

TIME=1.9778913E-03 SEC CYCLE= 950

Figure 82. Velocity Field

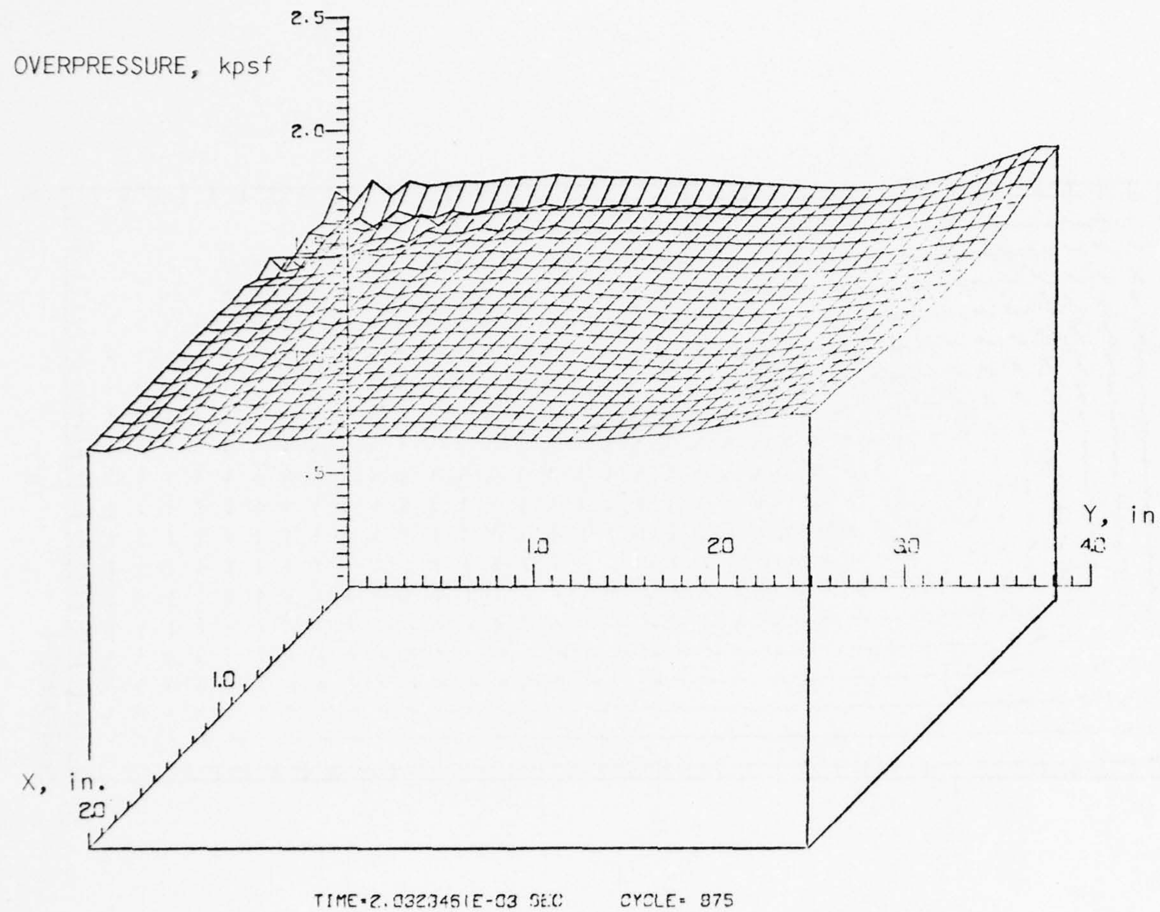


Figure 83. Pressure Field

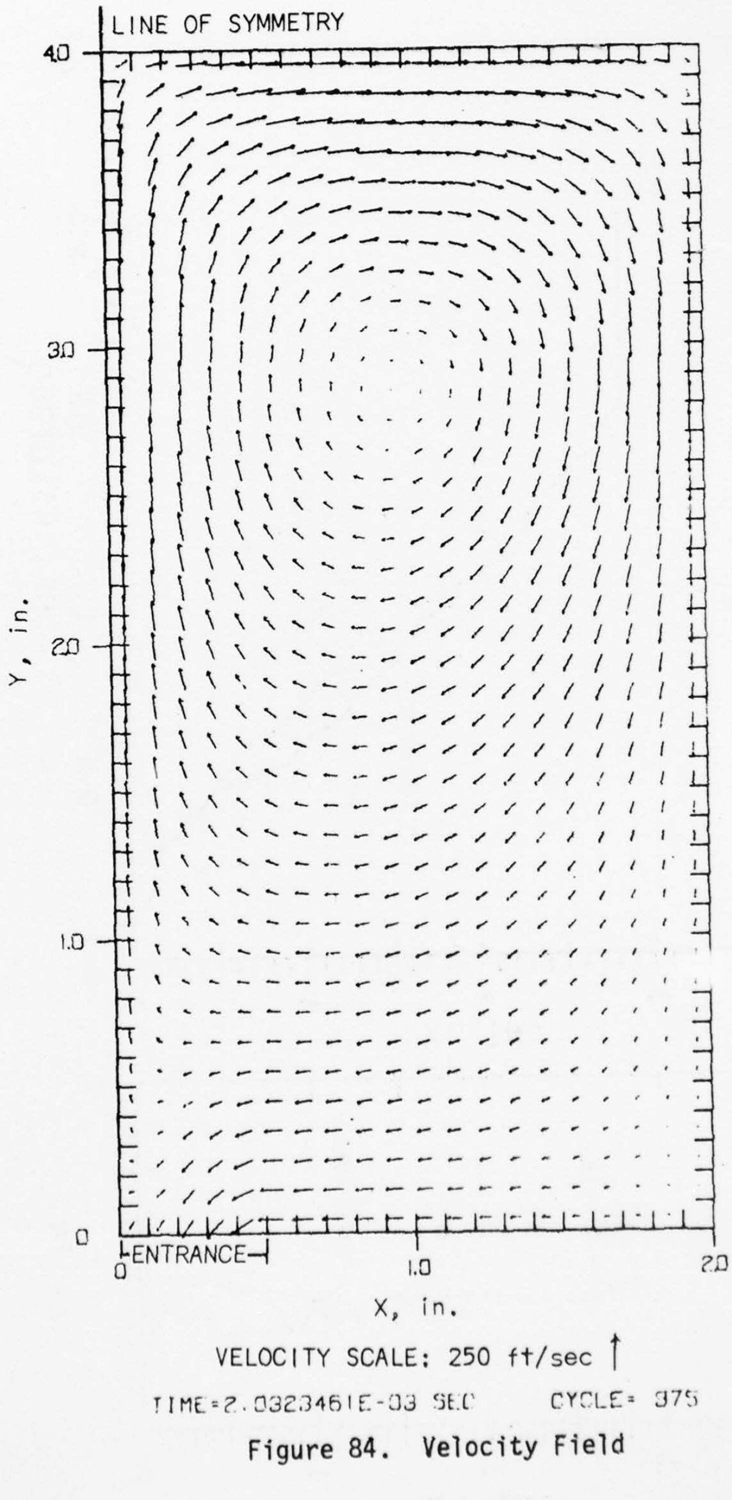


Figure 84. Velocity Field

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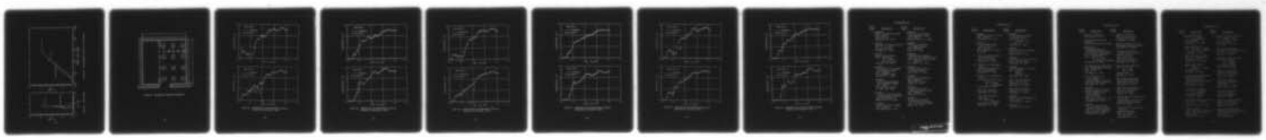

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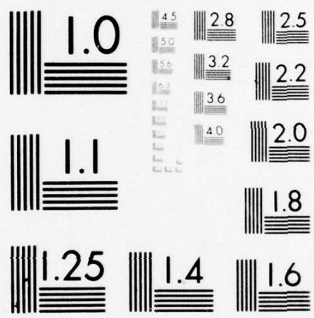

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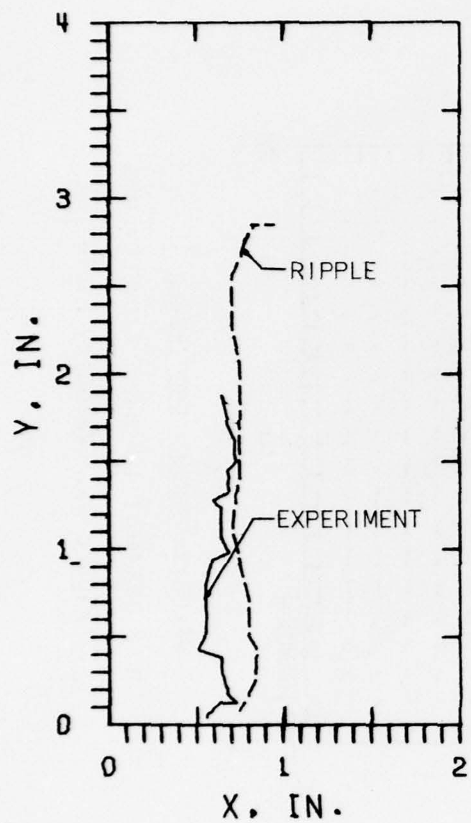


Figure 85. Vortex Paths

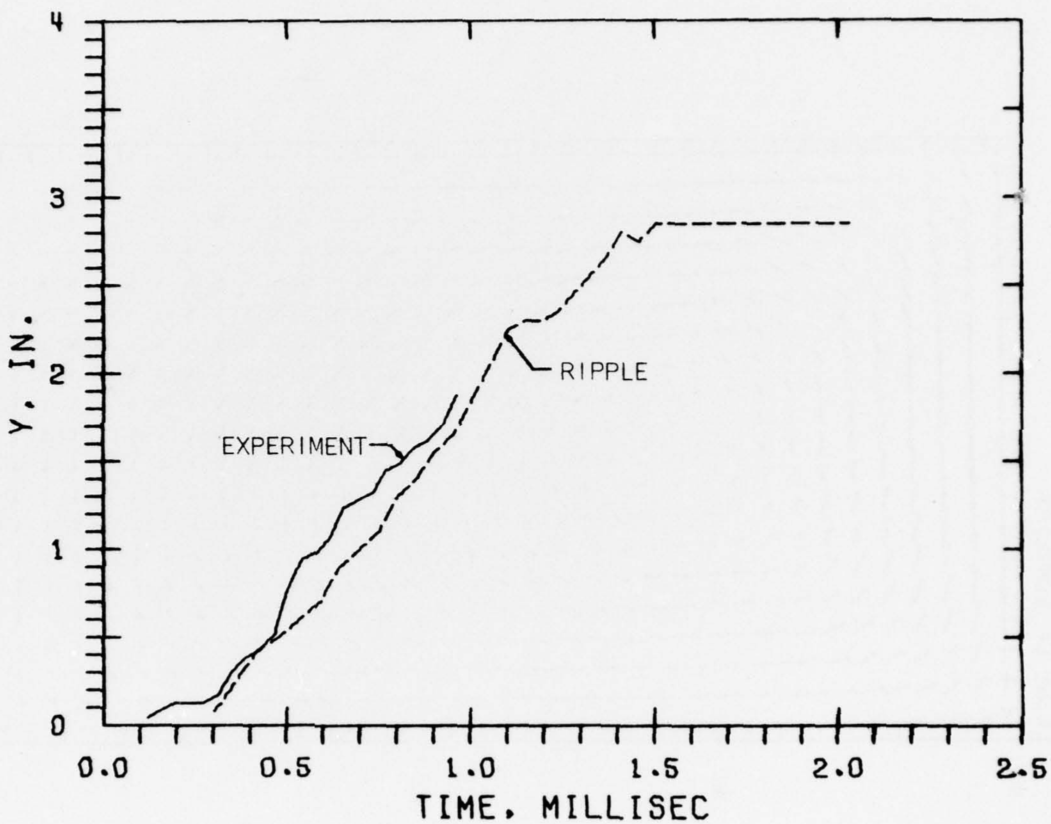


Figure 86. Y-Displacement Histories of the Vortex

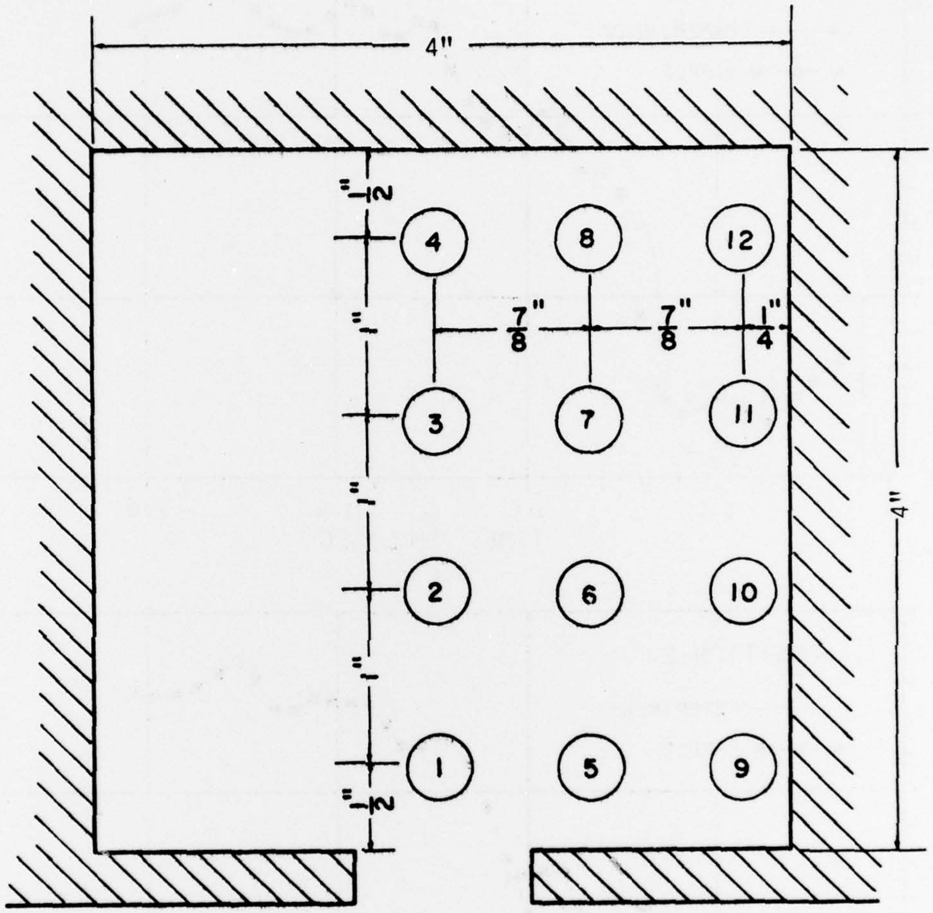
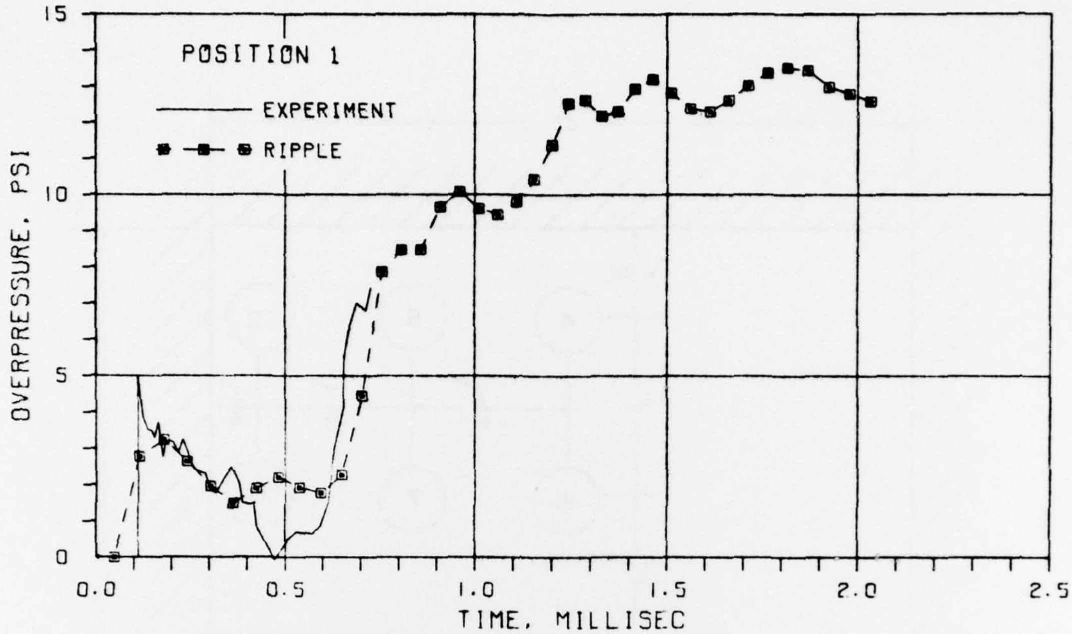


Figure 87. Positions of Pressure Transducers



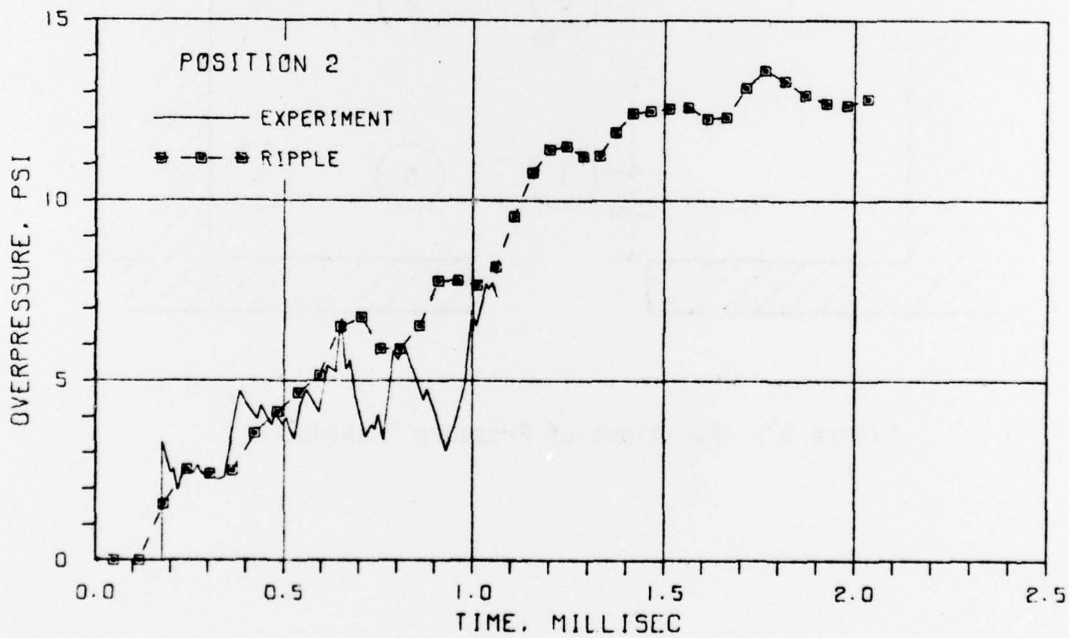
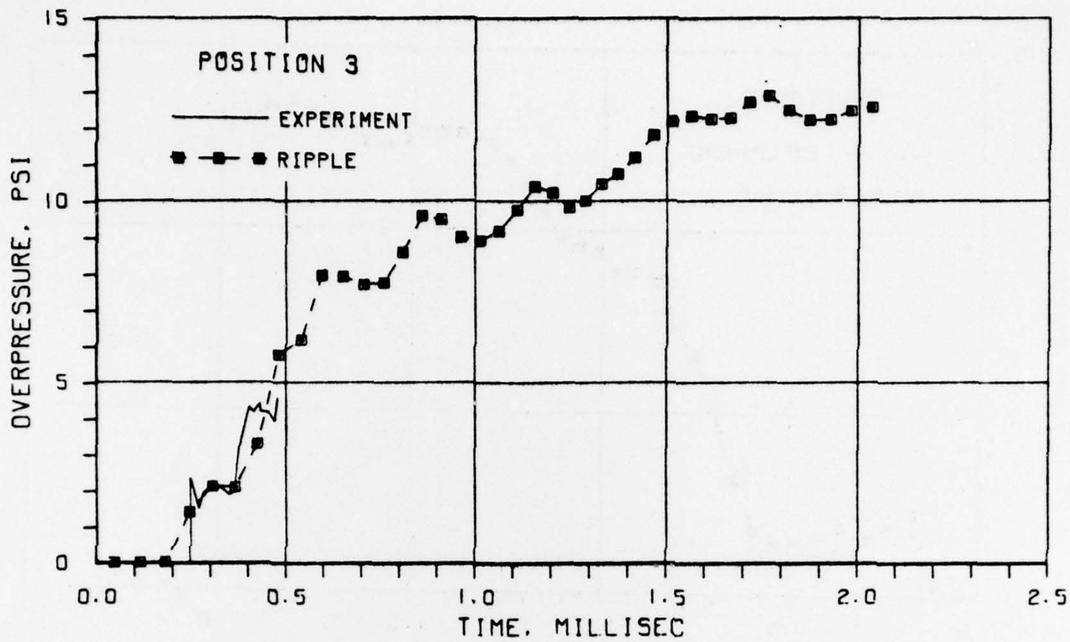


Figure 88. Computational and Experimental Pressure Histories at Positions 1 and 2



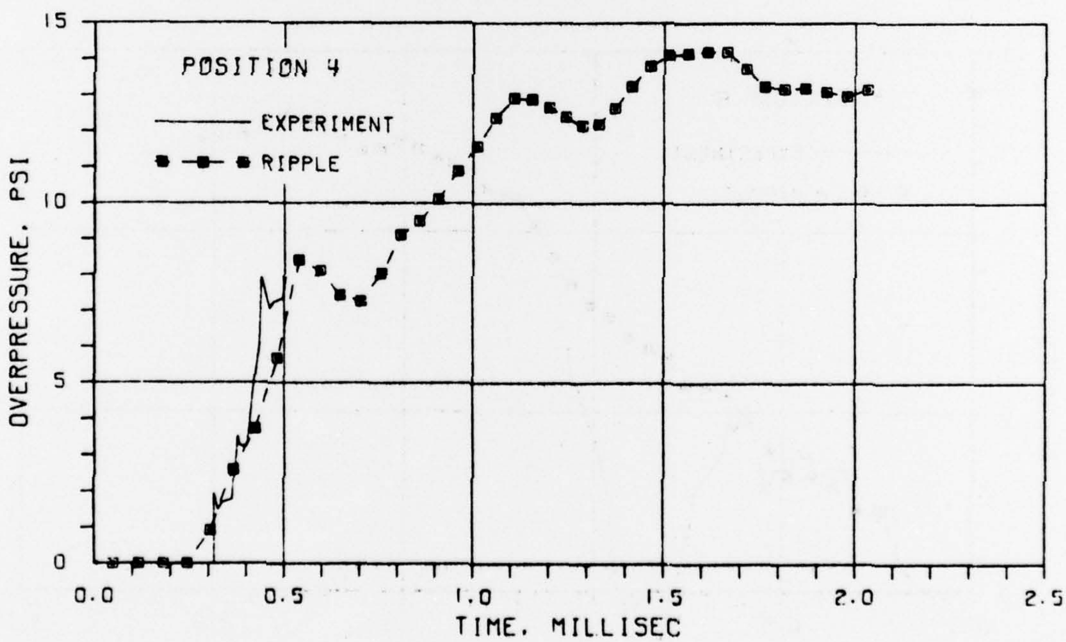


Figure 89. Computational and Experimental Pressure Histories at Positions 3 and 4

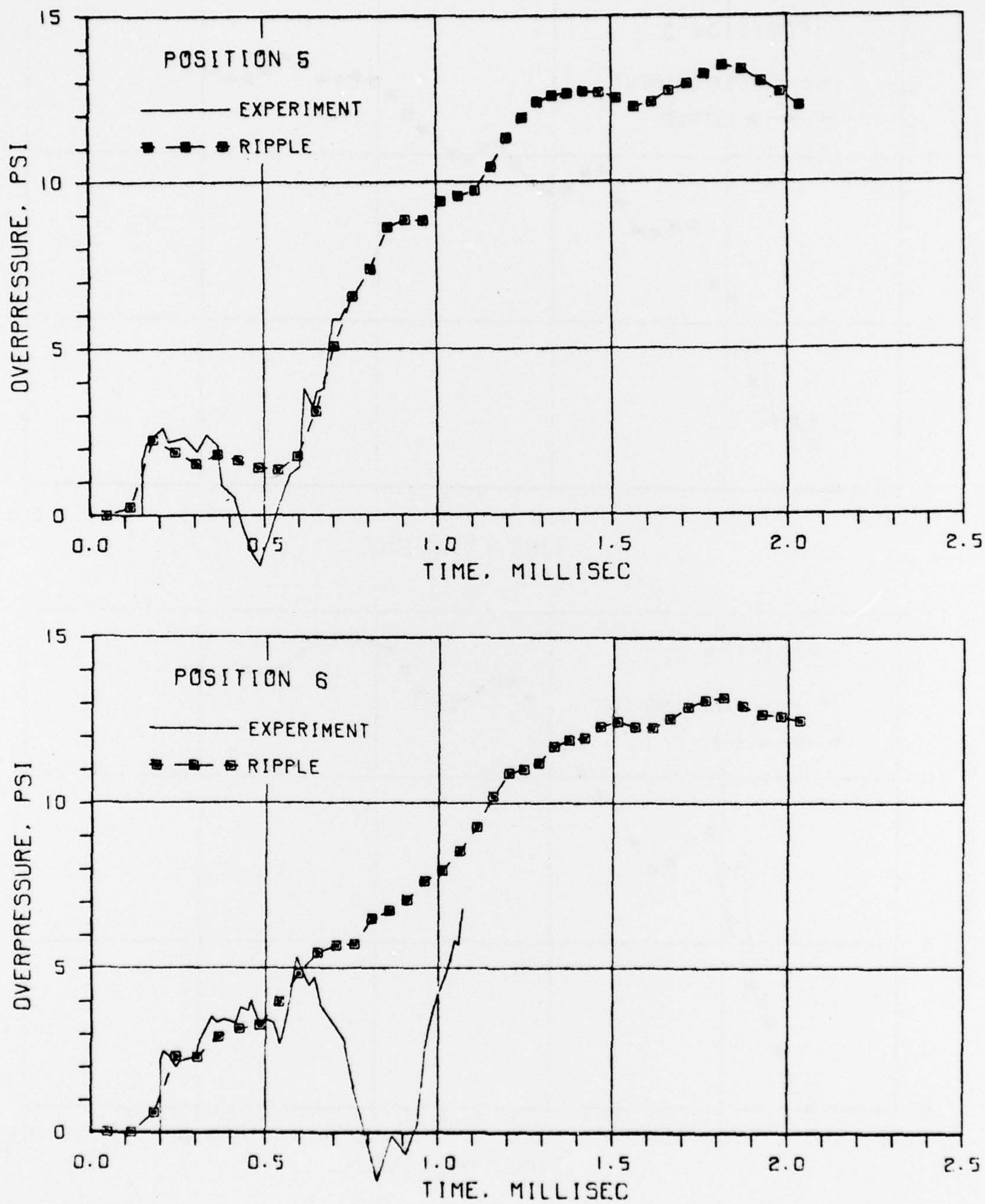


Figure 90. Computational and Experimental Pressure Histories at Positions 5 and 6

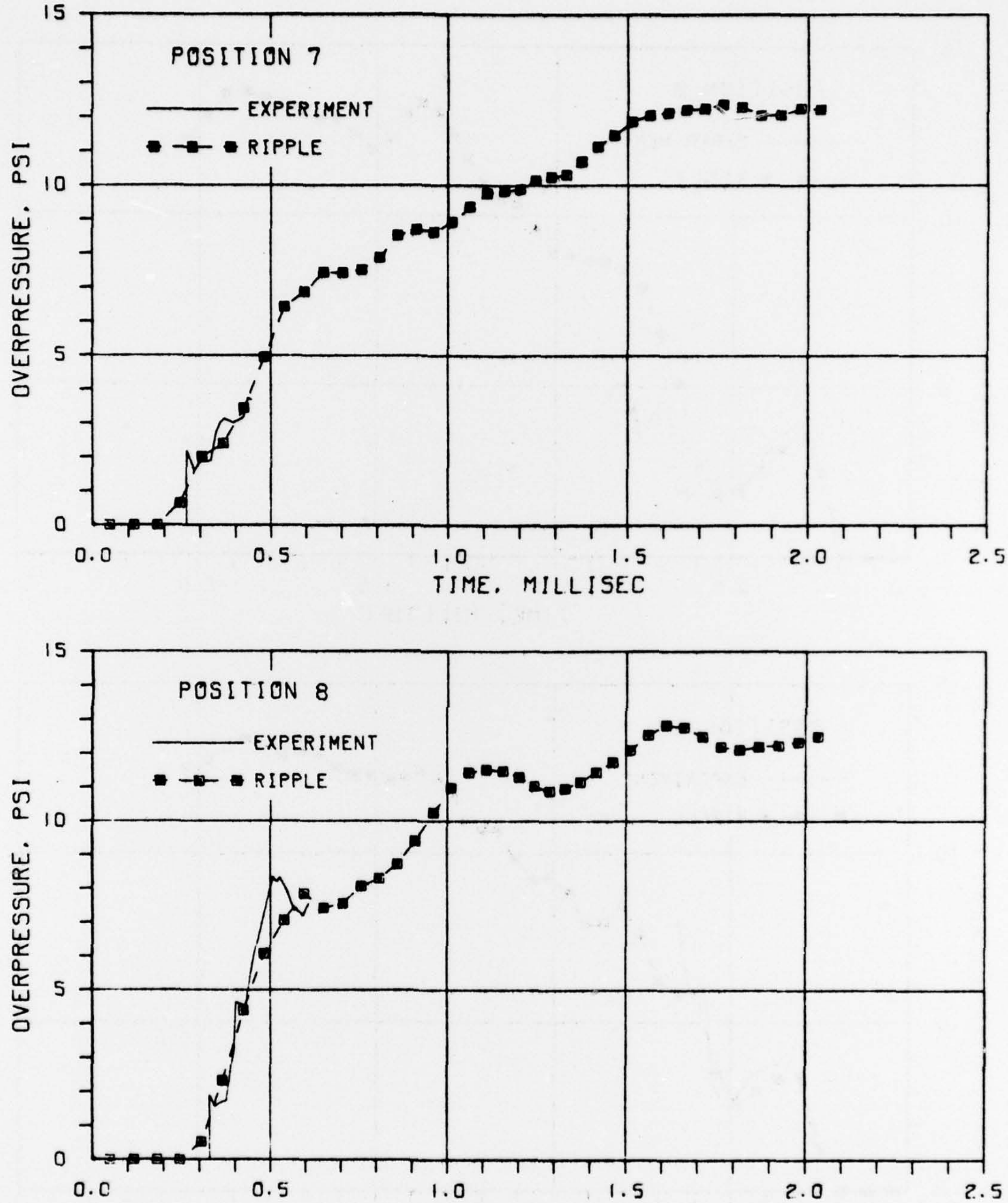


Figure 91. Computational and Experimental Pressure Histories at Positions 7 and 8

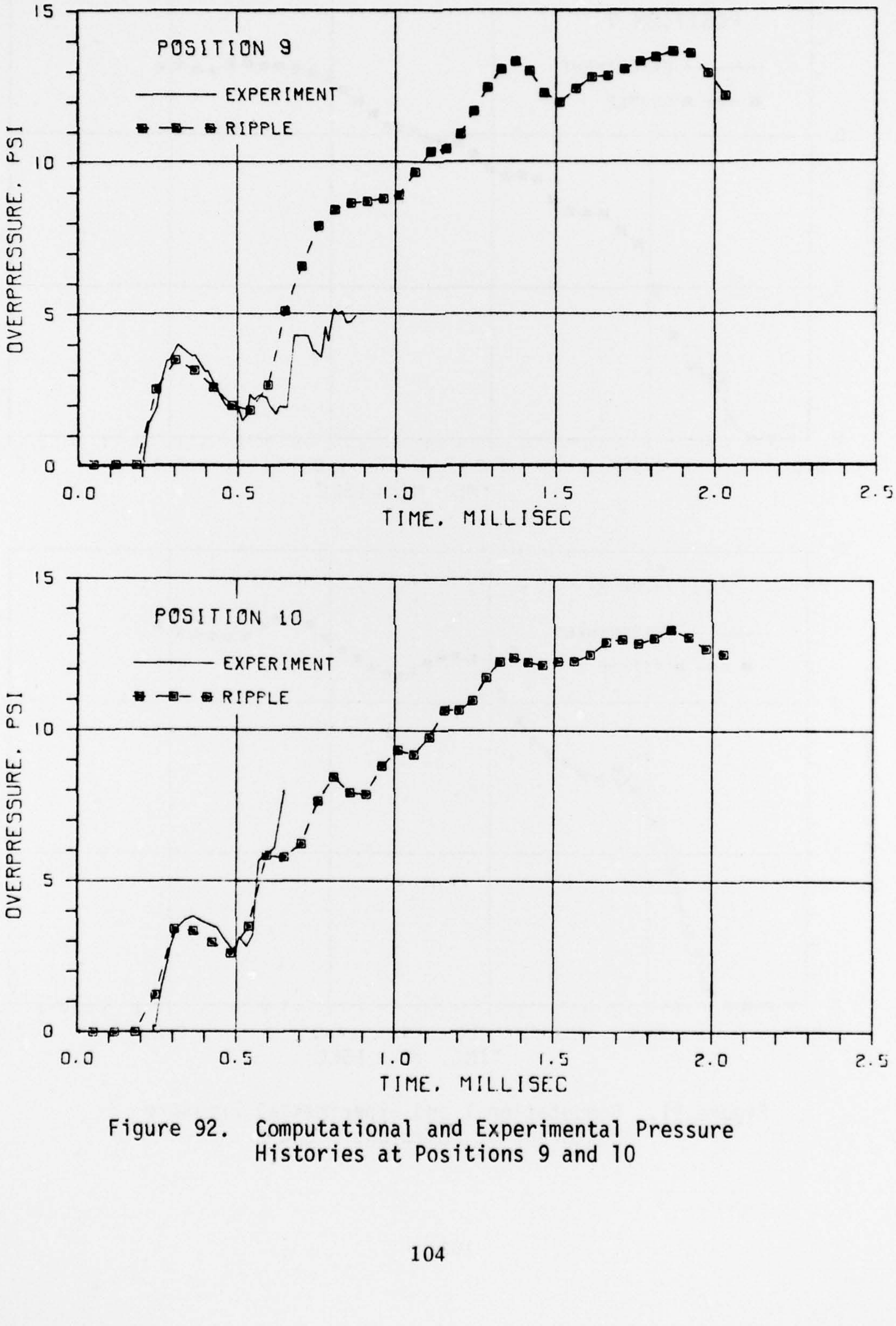
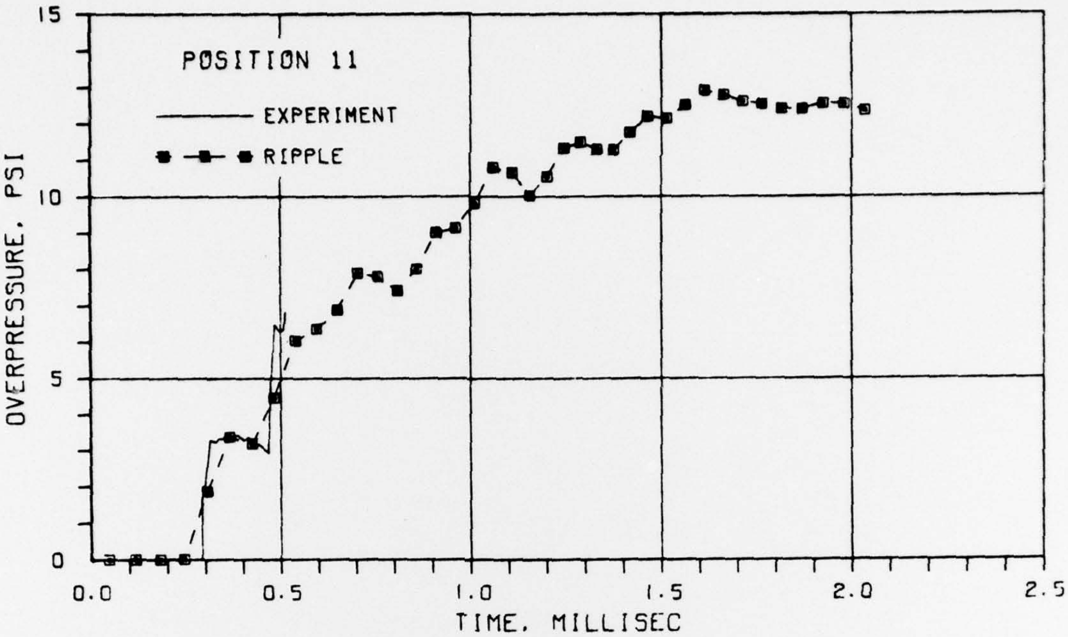


Figure 92. Computational and Experimental Pressure Histories at Positions 9 and 10



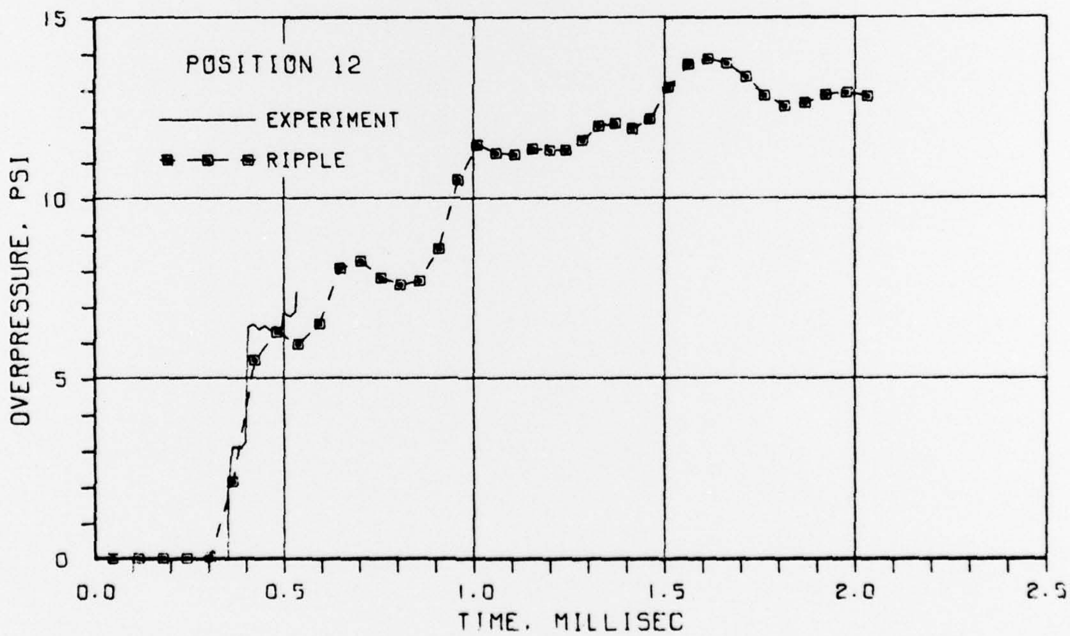


Figure 93. Computational and Experimental Pressure Histories at Positions 11 and 12

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